AFIT/GEE/ENV/94S-10

AN ANALYSIS OF ALTERNATIVE METHODS
OF MEASURING HAZARDOUS WASTE REDUCTION
PROGRESS AT THE AIR FORCE MATERIEL
COMMAND'S AIR LOGISTIC CENTERS

THESIS

Edward C. Finke

AFIT/GEE/ENV/94S-10

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

Accesion For	
NTIS CRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

AFIT/GEE/ENV/94S-10

AN ANALYSIS OF ALTERNATIVE METHODS OF MEASURING HAZARDOUS WASTE REDUCTION PROGRESS AT THE AIR FORCE MATERIEL COMMAND'S AIR LOGISTIC CENTERS

THESIS

Presented to the Faculty of theSchool of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fullfillment of the

Requirements for the Degree of

Master of Science in Engineering and Environmental

Management

Edward C. Finke

September 1994

Approved for public release; distribution unlimited

Acknowledgements

I am deply endebted to my loving wife, Teresa, for her encouragement, patience, and understanding during the times I had to focus soley on the research effort in lieu of other activities.

I am grateful to my research advisor, Major James Aldrich for providing his inspiration, insight, and guidance throughout the research process. Thanks also to Professor Dan Reynolds for devoting his statistical expertise and time in reviewing the document as a commitee member. I also wish to thank Mr. Gopal Annamraju, Mr. Matt Phillips, and Ms. Edna Williams at HQ AFMC for providing the necessary data that was the backbone of the research.

I would like to thank the entire class of GEE 94-S, as well as the ENV faculty and staff for their comraderie and friendship during the time we spent together. Special thanks go to my golfing partners: Dave, Ron, Bob, Jon, and Chris. The time shared on the course provided a refreshing break from the demands of academic pursuits.

Finally, I would like to dedicate this work to my father, Harry F. Finke Jr.; I would never have accomplished what I have in my life without his example, love, and support.

Table of Contents

Page

Acknowledgments....................................ii

List of Figures....................................v

List of Tables....................................vii

Abstract....................................vii

I. Introduction.................................... 1

Background.................................... 1
General Issue.................................... 2
Problem Statement.................................... 3
Purpose.................................... 4
Research Questions.................................... 4
Research Scope.................................... 4
Need for the Research Effort.................................... 6
Thesis Organization.................................... 8

II. Literature Review.................................... 10

Pollution Prevention Related Terms and Definitions.. 10
Pollution Prevention.................................... 10
Source Reduction.................................... 10
Hierarchy of Pollution Prevention.................................... 11
Waste Minimization.................................... 11
Historical Overview of the Development of Pollution Prevention.................................... 13
Benefits of Pollution Prevention.................................... 17
Air Force Goals.................................... 18
Current Air Force Hazardous Waste Disposal Metric... 19
AFMC Mission and Locations.................................... 19
Alternative Methods of Measuring Waste Reduction Progress.................................... 20
Actual Quantity Change.................................... 21
Activity Indexing Method.................................... 23
Regression Modeling Method.................................... 27

III. Research Methodology.................................... 32

Data Collection.................................... 32
Hazardous Waste Disposal Data.................................... 33
Production Activity Data.................................... 33
Analytical Tools.................................... 34

Page

Correlation 34
Box and Whisker Plot 35
General Methodology 38
Analysis Based on the Most Highly Correlated Activity Variables 40
Analysis Based on DPAHs 40
Multi-variable Regression Analysis 41
Proposed Metric Applied to the 1993 Quarterly Data 41

IV. Data Analysis and Presentation 43

Establishing the Relationship - Correlation Analysis 43
ALC-1 45
ALC-2 47
ALC-3 49
ALC-4 51
ALC-5 53
ALC-6 56
Comparative Analysis of the Alternative Methods 59
Based on the Most Highly Correlated Activity Variable 59
Analysis Based on DPAHs 68
Multi-variable Regression Analysis 74
Conclusions from the Comparative Analysis 78
Proposed Metric Applied to the 1993 Quarterly Data 80

V. Conclusions and Recommendations 84

Conclusions 84
Recommendations 85

Appendix A: Raw Data 87

Appendix B: Regression Equations 93

Bibliography 97

Vita 101

List of Figures

Figure Page

1. HW Disposal vs. DPAHs 1985-89 for a Hypothetical ALC 30

2. Box and Whisker Plot of the Percent Change in Hazardous Waste Disposal from the 1987 Baseline..... 37

3. HW Disposal and Number of Aircraft Serviced at ALC-1.. 46

4. Scatter Plot of HW Disposal vs. Aircraft at ALC-1... 47

5. HW Disposal and Number of Exchangeables at ALC-2.... 48

6. Scatter Plot of HW Disposal vs. Exchangeables at ALC-2.. 49

7. HW Disposal and Number of Aircraft Serviced at ALC-3.. 50

8. Scatter Plot of HW Disposal vs. Aircraft at ALC-3... 51

9. HW Disposal and Number of Exchangeables at ALC-4.... 52

10. Scatter Plot of HW Disposal vs. Exchangeables at ALC -4.. 53

11. HW Disposal and Number of Exchangeables at ALC-5.... 55

12. Scatter Plot of Exchangeables vs. HW Disposal at ALC-5.. 56

13. HW Disposal and Number of Engines Serviced at ALC-6.. 57

14. Scatter Plot of HW Disposal vs. Engines Serviced at ALC-6.................................. 58

15. Scatter Plot with Fitted Regression Line for ALC-1, 1985-89 Data.................................. 63

16. Box and Whisker Plots for the Various Methods Based on Highest Correlated Variables............... 67

Figure | Page

17. Box and Whisker Plots for the Various Methods Based on DPAHs.......... 79

18. Box and Whisker Plots for the Various Methods for Multi-variate Regressions.......... 78

19. Box and Whisker Plots for the Various Methods Based on Quarterly Data.......... 83

List of Tables

Table Page

1. Hazardous Waste Disposal and Man-hours from a Hypothetical process 7

2. Hazardous Waste and DPAHs Data for a Hypothetical ALC.. 22

3. Correlation Coefficients for the Listed Activity Variables to HW Disposal (Yearly Data 1985-1989).... 44

4. Yearly Percent Change in Hazardous Waste Disposal for the Various Methods............................. 61

5. Descriptive Statistics for Table 4 Percent Change Data... 65

6. Percent Change in Hazardous Waste Disposal for the Various Methods (DPAH Based)........................ 70

7. Descriptive Statistics for Table 6 Percent Change Data... 72

8. Yearly Percent Change in Hazardous Waste Disposal Mult-Variable Regression............................. 75

9. Descriptive Statistics for Table 8 Percent Change Data... 76

10. Quarterly Percent Change in 1993 HW Disposal for the Various Methods................................. 81

11. Descriptive Statistics for Table 10 Percent Change Data... 82

Abstract

Hazardous waste (HW) reduction progress in the Air Force (AF) is currently measured as a percent reduction from an established baseline year's amount. For example, the AF metric is to reduce HW off-site disposal by 25 percent from the 1992 baseline amount by 1996. Unfortunately, this goal does not reflect changes in activity levels at the bases. A base that experiences an increase in activities that generate HW may not achieve the goal despite having an aggressive pollution prevention program. Conversely, a base that experiences a significant decrease in HW generating activities may achieve the goal with little effort put toward pollution prevention.

This research investigated the relationship between aircraft related maintenance activity and the amount of HW disposed of by AFMC's ALCs. These ALCs, along with the Aircraft Guidance and Meteorology Center generate approximately 76 percent of the HW generated by the AF. The activity indexing and least squares curve fitting methods were used to predict the amount of HW that would have been disposed of based on the relative level of aircraft related maintenance activity had no pollution prevention efforts been implemented. These predictions were then compared to what actually occurred as the measure of HW reduction progress.

The results indicated that there is a moderate to strong correlation between HW disposal and aircraft related maintenance at five of the six bases studied. The activity indexing method based on an average ratio of HW to maintenance and the method of fitting a least squares regression line through the origin were determined to be the most useful methods.

An Analysis of Alternative Methods of Measuring Hazardous Waste Reduction Progress at the Air Force Materiel Command's Air Logistic Centers

I. Introduction

Background

Two vehicles traveling the same route to a common destination from the same starting point will have traveled the same distance. From the a distance perspective, the vehicles can be said to have made the same amount of progress. However, if one of those vehicles travels faster, relative to the other vehicle, it will reach the destination first. Hence, from a velocity perspective, the faster vehicle is said to have made greater progress because the journey took less time. The velocity of the vehicles provides a frame of reference from which to compare the relative progress of the vehicles.

Measuring pollution prevention progress is similar to the above analogy. Two firms operating in the same industry may achieve the same reduction of pollution (distance), but the level of production (velocity) of the two firms may differ. If one of the firms' production level increased relative to the previous period and the other's remained constant, the firm that experienced the increased production would be said to have made greater progress in reducing pollution. In this case, the level of production provides a frame of reference from which to judge progress.

The Air Force's pollution prevention metrics target an established percentage reduction of pollution from a baseline mass over a series of years. For instance, hazardous waste disposal reductions are currently assessed by measuring the percentage reduction of tons of hazardous wastes disposed off-site compared to the CY1992 baseline amount. This measurement is analogous to measuring distance rather than velocity because the relative level of activity is not considered. A more appropriate measure would take into consideration the relative amount of activity in determining progress.

General Issue

Measuring pollution prevention progress without considering relative levels of activity may not reflect true reduction efforts and may result in giving credit where credit is not necessarily due or not giving credit when credit is due. As a result, the current method of measuring hazardous waste reduction progress in the Air Force may not be reflective of pollution prevention efforts. Personnel reductions, mission changes, base realignment and closures, decreases or increases in depot maintenance activities, regulatory changes, and waste site cleanup efforts can all affect the amount of hazardous waste disposal. These changes may be seen at the base level, command level, within a wing, or throughout the entire Air Force. For example, large reductions of hazardous waste disposal may be measured at Base A that has a decrease in aircraft maintenance activities for a given year. Base B, on the other hand, may show a significant increase in hazardous waste disposal due to an increase in aircraft maintenance activities. Given the assumption that aircraft maintenance activities result in the generation of hazardous wastes, Base A would easily achieve their targeted percentage reduction with little or no effort put toward pollution prevention, whereas Base B may not achieve their reduction goals despite having an aggressive pollution prevention program. Clearly, the current metric would not provide a fair assessment of the relative effectiveness of the pollution prevention programs at these two hypothetical bases, given the circumstances described above. The current metric would provide a consistent measure only if the Air Force mission activities were constant.

Problem Statement

The current Air Force method of assessing hazardous waste reduction progress does not provide a fair and accurate means of assessing the relative effectiveness of pollution prevention efforts because it does not account for changes in activity levels. Increases or decreases in activity levels may be associated with a respective increase or decrease in the generation and subsequent disposal of hazardous wastes. Additionally, the usefulness of applying known alternative waste reduction measurements within the Air Force has not been investigated.

Purpose

The purpose of this research is to develop a revised metric for measuring waste reduction progress that accounts for changes in hazardous waste producing activities.

Research Questions

1. Is there a statistically significant relationship between the amount of hazardous waste disposal and various measures of aircraft maintenance activity?

2. How does the current Air Force measurement method compare to alternative methods of measuring pollution prevention progress?

Research Scope

Air Force Materiel Command (AFMC) manages approximately 51% of the total Air Force budget (AFMC, 1993a:8). Furthermore, AFMC generates approximately 80% of the total amount of hazardous waste generated by the Air Force

(Annamraju, 1993). In 1992, the five Air Logistic Centers (ALCs) within AFMC produced approximately 95% of the hazardous wastes generated by AFMC as a whole. Therefore, those five locations manage 76% of the total hazardous waste generated by the Air Force. Given the enormous contribution of these installations to the hazardous waste generated by the Air Force, limiting the study to only these depot maintenance bases will focus on the entities which have the greatest potential for pollution reduction. Also, the ALCs perform large scale industrial operations that are comparable to a private sector industrial firm. The alternative methods of measuring pollution prevention progress investigated were developed primarily for large scale industrial type operations.

This research analyzed the relationship between the hazardous waste disposal data from 1985 to 1993 to various measures of activity at the AFMC bases that perform depot level maintenance on aircraft, aircraft engines, exchangeable aircraft parts, and missiles. This research will determine if there is a significant relationship between the activity levels at the five ALCs, as well as the Aerospace Guidance and Meteorology Center (AGMC), and the amount of hazardous waste disposed of by those locations.

Need for the Research Effort

The Air Force goal is for each base to reduce its hazardous waste disposal fifty percent by CY1999 from the CY1992 baseline (Department of the Air Force, 1993:5). Due to changes in activity levels at the bases, this method of assessing waste reduction progress may not reflect true waste reduction efforts. For example, assuming that no pollution prevention efforts were pursued, significant reductions in aircraft maintenance activity logically would result in reduced amounts of HW requiring disposal, but this reduction would not be the result of any pollution prevention activities. Conversely, an increase in HW disposal at a base may in fact be due to increased aircraft maintenance activity. The object of the metric is not to simply assess a change in hazardous waste disposal, but to assess the effectiveness of pollution prevention efforts.

Fortunately, this problem can be avoided by using an alternative method of measuring waste reduction progress. For example, changes in HW disposal resulting from changes in production are removed from the measurement when the activity indexing method is applied (Baker et. al., 1991:5-6).

Table 1 is a hypothetical presentation of the yearly amount of hazardous waste disposal and the amount of man-hours for a given process that generates hazardous waste. From the table, it can be calculated that there was a ten percent decrease in hazardous waste disposal in 1992 from the 1987 level. However, there was also a fifty percent decrease in man-hours in 1992 from 1987. Logically, if all other parameters remained the same, there should have been fifty percent less (500 tons) hazardous waste disposed of in 1992. Given that there should have been fifty percent less waste, there was actually an eighty percent increase in 1992 from the 500 tons that was expected based on the decreased level of production. This example illustrates how measuring the percentage reduction without accounting for the changes in activity can confound the measurement and indicate progress that is not the result of pollution prevention efforts.

TABLE 1. HAZARDOUS WASTE DISPOSAL AND MAN-HOURS FROM A HYPOTHETICAL PROCESS

YEAR	HW DISPOSAL (tons)	MAN-HOURS (000s)
1987	1000	10000
1992	900	5000

Hatfield and Ott examined the current legislation regarding the measurement of source reduction and came to the following conclusion: "Although many federal and state laws require that source reduction be documented, many of these laws do not explicitly state how to quantify source reduction" (Hatfield and Ott, 1993:7). They indicate that accurate quantification is further confounded by changes in production levels, regulations, and enforcement policies.

Moreover, in a study conducted by Bower and Jacobson, defense contractors and other corporations were interviewed concerning their methods of tracking waste reduction progress (Bower and Jacobson, 1993:192). The responses indicated that no firms used "...any sophisticated measurement systems to quantify progress," and that most firms used measures of total waste reduction that were strictly in terms of volume or weight changes, without regard to changes in production levels.

In contrast, the EPA's guidance on what constitutes a waste minimization program strongly suggests that adjusting the measurement of waste reduction progress to account for changes in production levels is preferable if there is a strong correlation between waste quantity and production (Federal Register, 1993:31117).

The above references indicate that adjusting for changes in production levels is a valid and encouraged technique for measuring waste reduction progress.

Thesis Organization

This thesis is divided into five chapters. Chapter I provides a brief overview of the problem, research purpose and scope, as well as the need for the research effort.

Chapter II discusses the history and development of the pollution prevention concept, and describes in detail the alternative methods of measuring hazardous waste reduction progress. It addresses the pertinent regulations, the history of pollution prevention efforts in the Air Force, and how pollution prevention progress is currently measured. Chapter III explains the research methodclogy used to answer the research questions. Chapter IV presents and discusses the results of the data analysis using the methods described in Chapter III. The conclusions drawn from the research effort and suggestions for further study are discussed in Chapter V. An appendix including the raw data is included for reference purposes.

II. Literature Review

Pollution Prevention Related Terms and Definitions

Pollution Prevention. Pollution prevention focuses on reducing or eliminating pollution at its source rather than treating the waste in some manner after it has been generated. Pollution prevention is defined as:

> The use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous materials, energy, water, or other natural resources, and practices that protect natural resources through conservation and more efficient use. (Freeman et al., 1992:619)

Pollution prevention efforts include actions such as process changes and raw material substitutions.

Source Reduction. The term source reduction refers to actions that reduce a waste stream at the source prior to its generation. EPA defines source reduction to include:

> Any practice which (i) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and
> (ii) Reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants. (Federal Register, 1993:31115).

Source reduction includes: modifications to equipment, processes, procedures, or technology; product redesign or reformulation; raw material substitution; and improvements in housekeeping, maintenance, training, or inventory control (Federal Register, 1993:31115).

Hierarchy of Pollution Prevention. The EPA's hierarchy of preferred approaches to pollution prevention as outlined in the Pollution Prevention Act of 1990 can be described as follows (United States Congress, 1990:3):

1. Prevent or reduce pollutants at the source whenever feasible.

2. If source reduction is not practical, recycle the pollutant in an environmentally safe manner.

3. Treat the pollutant in an environmentally safe manner.

4. Finally, as a last resort, dispose of the pollutant in an environmentally safe manner.

As can be seen from the order of preference, it was Congress's intention that source reduction be pursued to the greatest extent possible, with recycling as the second alternative of choice.

Waste Minimization. Waste minimization carries a different meaning by including not only source reduction, but environmentally sound recycling as well (Federal Register, 1993:31115). Freeman and others describe the term waste minimization in their *Critical Review of Industrial Pollution Prevention* as including any source reduction or recycling activity performed by the generator of a waste that results in a reduction of total volume or toxicity of that waste (Freeman et al., 1992:619). Waste minimization is defined as "the reduction, to the extent feasible, of hazardous waste that is generated or subsequently treated, stored, or disposed (Freeman et al., 1992:619).

The EPA provides several examples of actions which are not considered waste minimization in their *Guidance to Hazardous Waste Generators on the Elements of a Waste Minimization Program* (Federal Register, 1993:31115). For example, the use of an air stripper to evaporate volatile organic compounds from wastewater is not waste minimization because the hazardous material is only transferred from one environmental media to another. Additionally, actions which reduce waste volume do not constitute waste minimization unless, concentrating the waste is necessary in order to recover a "useful constituent prior to treatment and disposal." Additionally, dilution to avoid classification as a hazardous waste is not considered waste minimization, unless it is necessary in order for recycling or the recovery of a useful product. By excluding these actions from waste minimization, the EPA is trying to reduce the potential transfers of hazardous wastes to other environmental media.

Historical Overview of the Development of Pollution Prevention

The number and complexity of federal and state environmentally related regulations continues to increase. In 1985, there were approximately 7,000 pages of federal environmental laws and regulations. By 1988, this number had grown to 10,000 pages (Freeman et al., 1992:622). The sheer number of applicable statutes makes compliance with the laws and associated regulations difficult for private industry, as well as the government itself.

The regulation of hazardous wastes essentially began with the Resource Conservation and Recovery Act (RCRA) of 1976. This act addressed the generation, storage, transportation, treatment, and disposal of hazardous wastes, but did not encourage or mandate hazardous waste reduction (Masters, 1991:185). This Act has its origins in the 1965 Solid Waste Disposal Act and the 1970 Resource Recovery Act.

RCRA was amended in 1984 by the Hazardous and Solid Waste Amendments (HSWA). HSWA established the requirement for a generator of hazardous waste to establish a waste minimization program to reduce the amount of waste generated. In HSWA, Congress declares, "The elimination or reduction of hazardous wastes at the source should take priority over the management of hazardous wastes" (Federal Register, 1993:31114). It is in this document that the concept of the pollution prevention is first established.

Section 1003 (b) of RCRA states:

> It is to be the policy of the United States that, whenever feasible, the generation of hazardous waste is to be reduced or eliminated as expeditiously as possible. Waste that is nevertheless generated should be treated, stored, or disposed of so as to minimize the present and future threat to human health and the environment. (Federal Register, 1993:31115)

The law requires that all generators of hazardous wastes certify on their waste shipment manifests that they have a waste minimization program in place. In addition to the manifest certification requirement, HSWA requires that large quantity generators and owners and operators of treatment storage and disposal facilities file a biennial report to the EPA. This report compares the quantities and types of hazardous wastes generated during the reporting period to the previous period, and outlines efforts to reduce the volume and toxicity of wastes (Theodore and McGuinn, 1992:110). This portion of the law had little effect on overall waste generation levels because no specific goals were established and enforcement of the waste minimization requirement was difficult.

The EPA's Science and Advisory Council noted in a 1988 document that many of the most serious problems facing the environment today cannot be solved through the implementation of end-of-pipe controls and that the EPA should shift its emphasis towards preventing pollution at its source (Freeman et al., 1992, 618). Bush identifies several reasons for the emergence of the pollution prevention concept in a 1992 article titled *Measuring Pollution Prevention Progress: How Do We Get There from Here?* (Bush, 1992:431). She describes several realizations by the government and industry that lead to the evolution of pollution prevention. First, there was a realization of the technical limitations of the end-of-pipe regulation of environmental problems, coupled with the rising costs of treatment and disposal. Second, there was the realization that pollutants were often merely shifted from one environmental media to another under the end-of-pipe approach. Third, the 1984 HSWA established the regulatory concept of waste minimization. Fourth, the potentially large costs associated with the cleanup of past hazardous waste sites makes pollution prevention an economically attractive option to waste generation in most cases.

As a result, the Pollution Prevention Act (PPA) of 1990 requires that pollution prevention be national policy. This law also instituted the EPA's Office of Pollution Prevention to carry out the functions required by the act (Theodore and McGuinn, 1992:110). To date, no specific EPA regulations have been promulgated concerning the Pollution Prevention Act of 1990; however, the Act establishes the pollution prevention hierarchy and requires that facilities who report Toxic Release Inventory data pursuant to Section 313 of the Superfund Amendments Reauthorization Act to also provide information on pollution prevention activities in those reports.

Because the purpose of pollution prevention is to reduce or eliminate pollution generation at the source, it is in contrast to historical end-of-pipe or top-of-stack controls previously promulgated by the EPA. These end-of-pipe control measures may be reaching the technological limits of their effectiveness at reducing pollution in many areas of environmental concern. The gross problems, such as the pollution of Lake Erie, have been addressed through end-of-pipe controls; however, there is still much improvement which can be achieved through pollution prevention. For example, an air pollution control device used to control volatile emissions from a degreasing process is capable of controlling only a finite percentage (i.e. 99%) of those emissions. The only way to reduce or eliminate the remaining one percent of those emissions is to reduce or eliminate the use of the volatile compound used in the degreasing process. This can be done by substituting an aqueous based degreaser for the volatile degreaser.

In addition to the federal regulations, many states have passed laws requiring industry to reduce hazardous waste generation. More than 15 states have established laws that require industry to prepare written pollution prevention plans (Hatfield and Ott, 1993:7). California was one of the first states to mandate such actions. Its law, the Hazardous Waste Source Reduction Act, requires generators in California to reduce hazardous and non-hazardous wastes 25 percent by 1995 and 50 percent by 2000 from 1990 levels (AFCEE, 1993:151).

Benefits of Pollution Prevention

An effective pollution prevention program provides many benefits to the participating organization, its employees, and society as a whole. EPA's *Facility Pollution Prevention Guide* describes these benefits as reduced risk of criminal and civil liabilities, as well as toxic tort cases; reduced operating and waste disposal costs; improved employee morale; enhanced corporate public image; and protection of human health and the environment (USEPA, 1992:1-4).

Pollution prevention reduces the use of hazardous substances. As a result, a generator avoids regulation of those substances by federal and state hazardous waste regulations; therefore waste disposed of is not subject to potential costly cleanup actions under RCRA and CERCLA. Additionally, by avoiding the handling, transportation, and disposal of a hazardous waste, a generator avoids potential lawsuits resulting from transportation mishaps, as well as the costs associated with transporting and disposing of the waste as hazardous waste versus solid waste. Furthermore, by not using a hazardous substance during production, the generator avoids workers' compensation costs and the risks associated with employee exposure to those chemicals.

Air Force Goals

Air Force Policy (AFP) Directive 19-4 establishes specific goals for pollution prevention in the Air Force and outlines metrics to measure progress toward those goals (Department of the Air Force, 1992:1-3). This policy establishes the requirement to prevent at the source, to the greatest extent possible, environmentally harmful discharges to the air, land, surface water, and ground water. It encourages recycling and the use of non-hazardous product substitution whenever possible. It also requires the reduction of hazardous and municipal solid waste disposal, and the proactive procurement of recycled products.

The three main areas that are assessed by the pollution prevention metrics described in AFP 19-4 include: hazardous substance usage, waste releases to the environment, and the acquisition of recycled products. Included in the hazardous substance usage category are the sub-categories of ozone depleting compound (ODC) use, the EPA's 17 Industrial Toxics Project (ITP) substance use, and the EPA's Toxic Release Inventory (TRI) substance use. Included in the waste releases category are the sub-categories of hazardous waste disposal, municipal solid waste disposal, air pollutant emissions, and water pollutant releases (Department of the

Air Force, 1992:1-3). The metric that this research focuses on is the hazardous waste disposal metric.

Current Air Force Hazardous Waste Disposal Metric

Compliance with the directive to reduce hazardous waste disposal is currently assessed by measuring the percent reduction (based on weight) of off-site hazardous waste disposal from the calendar year (CY) 1992 baseline quantity (Department of the Air Force, 1993:5). Specific goals are to reduce off-site hazardous waste disposal by 25% from the CY1992 baseline by 1996 and a 50% reduction from the CY 1992 baseline by 1999. Prior to AFP 19-4, AFMC had established similar goals for the reduction of hazardous waste disposal. Specifically, the AFMC goal was to reduce off-site hazardous waste disposal by 50 percent from the CY1987 baseline by CY1992.

AFMC Mission and Locations

The mission of the Air Force Materiel Command is to provide a "cradle-to-grave" management of the Air Force's weapons systems and is referred to as Integrated Weapon System Management (AFMC, 1993b:4). AFMC resulted from the merger of the Air Force Logistics Command with the Air Force Systems Command on 1 July 1992 (AFMC, 1993b: ii). The command, headquartered at Wright-Patterson Air Force Base, is the primary organization responsible for managing all aspects of a weapons system throughout its lifetime, including its initial design, operational maintenance and support, and decommission and disposal. Additionally, the command provides support for all Air National Guard and US Air Force Reserve activities, and provides support for other US and Allied military forces and the National Aeronautics and Space Administration (1992 Annual Report, i).

The role of the five ALCs along with the AGMC is to provide the necessary logistics management to keep the Air Force's aircraft, missiles, and support equipment in proper operating condition (1992 Annual Report, i). The five ALCs are located at Tinker Air Force Base (AFB), Oklahoma; Hill AFB, Utah; Kelly AFB, Texas; McClellan AFB, California; and Robins AFB, Georgia. These centers are also known as Oklahoma City ALC (OC-ALC), Ogden ALC (OO-ALC), San Antonio ALC (SA-ALC), Sacramento ALC (SM-ALC), and Warner-Robins ALC (WR-ALC), respectively. The AGMC is located at Newark AFB in Newark, Ohio.

Alternative Methods of Measuring Waste Reduction Progress

There are several established alternative methods for measuring waste reduction progress. The most commonly used methods include: actual quantity change (the current Air Force method), adjusted quantity change (activity indexing), and throughput ratio. All of these commonly used alternative methods make certain assumptions that affect their accuracy under various circumstances (Baker et al., 1991:11-15).

The throughput ratio, which is a measure of how efficiently materials are used in a process, was not investigated in this research due to the lack of readily accessible and consistent historical hazardous material usage data. The throughput ratio equals the amount of a chemical used as raw material in a process divided by the amount of that chemical generated as hazardous waste (Baker et. al., 1991:15). This measure involves materials accounting and mass balances in a process to determine the efficiency of material usage. In order to use this measure, micro-level, process specific hazardous material usage and hazardous waste disposal data would have been required.

As another potential alternative method of measuring pollution prevention progress, the author of this thesis investigated the use of least squares curve fitting to arrive at a regression equation to predict the amount of hazardous waste disposal. The difference between the actual observed amount and the predicted amount of hazardous waste disposal was the measure of pollution prevention progress.

Each of the alternative methods investigated in this research are described below.

Actual Quantity Change. The actual quantity change is simply the amount of waste disposed of in the current year minus the amount of waste disposed of in the baseline year

(Baker et. al., 1991:5). The actual quantity change was converted to a percent change from the baseline year in order to be consistent with the current Air Force method.

$$\text{Actual Quantity Change} = \frac{\text{Current Quantity - Baseline Quantity}}{\text{Baseline Quantity}} * 100$$

As an example of the actual quantity change method, consider the data shown in Table 2 for a hypothetical ALC. Seven-hundred and twenty tons of hazardous waste were disposed of in 1992, compared to 1180 tons in 1987. Thus, the resulting percent change from the 1987 baseline was -39% as demonstrated by the calculation below. The column labeled DPAHs in the table refers to the number of direct product actual hours. DPAHs is a measure of the total number man-hours dedicated to aircraft related maintenance.

$$\frac{(720-1180)}{1180} * 100 = -39\%$$

TABLE 2

HAZARDOUS WASTE AND DPAHs DATA FOR A HYPOTHETICAL ALC

YEAR	HAZARDOUS WASTE DISPOSAL (tons)	DPAHs (000s)
1985	1390	6500
1986	1310	6020
1987	1180	5500
1988	990	4900
1989	900	4000
1985-89 AVG.	1154	5384
1992	720	3650

This actual quantity change method does not consider the difficulty in implementing a given source reduction activity, changes in production efficiency or levels, or reductions in toxicity (Baker et al., 1991:5). As a result, this method overstates pollution prevention progress if production levels decrease, and understates pollution prevention progress when production levels increase.

The advantage of using this method is that it is simple to calculate. The disadvantages of this method is that it does not provide information on what portion of the change is attributable to pollution prevention and waste minimization activities.

Activity Indexing Method. The activity indexing method, or adjusted quantity change, accounts for changes in waste generation that result from changes in activity (Baker et. al., 1991:5). As the name suggests, the ratio of the activity levels for the years of interest are used to establish the index. In order to calculate the adjusted quantity change, the previous year's quantity of waste is multiplied by an activity index to obtain an predicted quantity of waste for the baseline year. The activity index is the ratio of production levels between the current year and the previous or baseline year. Again, the measure was converted to a percent change in order to maintain consistency for comparison purposes.

$$\text{Activity Index} = \frac{\text{Activity Level Current Year}}{\text{Activity Level Baseline Year}}$$

$$\text{Adjusted Quantity Change} = \frac{(\text{Current Quantity} - (\text{Baseline Quantity} * \text{Activity Index})}{\text{Baseline Quantity} * \text{Activity Index}} * 100$$

The data from Table 2 is again used to demonstrate this method of assessing waste reduction progress. DPAHs at the hypothetical ALC were 5,500,000 and 3,650,000 in 1987 and 1992, respectively. Applying the activity index equation results in an activity index of 0.66. The predicted amount of hazardous waste which should have been disposed of in 1992 given that no pollution prevention actions were implemented is 779 tons which is obtained by multiplying the activity index by the 1987 amount of hazardous waste disposal (1180 tons). The percent change using this method was -7.6 percent, which is calculated by applying the adjusted quantity change equation as demonstrated below:

$$\frac{(720 - 779)}{779} * 100 = -7.6\%$$

This value indicates that the reduction in HW disposal due to pollution prevention efforts in 1992 from 1987 was approximately 8 percent. The 31 percent difference from the actual quantity change method is attributable to the reduction in aircraft related maintenance activity. Of course, this assumes that the ratio of HW disposal to DPAHs is representative of the relationship between the two variables prior to pollution prevention's implementation.

The activity indexing method can also be applied by establishing the baseline quantity as the average amount of hazardous waste disposal for a given number of years. The activity index is similarly calculated as the activity level for the year of interest divided by the average level of activity for the same number of years that the baseline quantity is averaged over. For example, the average DPAHs and hazardous waste disposal for the period 1985 to 1989 at the hypothetical ALC were 5,384,000 and 1154 tons, respectively. Hence, the activity index was 0.68 (3,650,000/5,384,000) and the predicted amount of hazardous waste disposal for 1992 was 785 tons (0.68*1154). The resulting percent change using this method was -8.3 percent as demonstrated in the calculation below.

$$\frac{(720-785)}{785} * 100 = -8.3\%$$

The activity indexing method of assessing waste reduction progress assumes: waste generation and the activity level are linearly related, no fixed quantities of waste are generated independently of activity levels, no factors other than the activity level and waste reduction efforts affect the quantity of waste generated, and the measure of activity and waste disposal is consistent over time (Baker et al., 1991:5-6).

The assumption that hazardous waste generation and the activity levels are perfectly linearly related will almost never be realized. This would require a correlation coefficient of 1.0. The closer the correlation coefficient is to 1.0, the better the method is at determining the effects of pollution prevention activities.

The second assumption that no quantities of waste are generated independently of activity levels is a reasonable assumption for the ALCs. As discussed in chapter I, the ALCs account for 76 percent of the total hazardous waste disposal Air Force wide. Any hazardous waste generated independent of depot maintenance activities at an ALC is dwarfed in comparison to the hazardous waste generated by the depot maintenance actions. Furthermore, the majority of activity at an ALC location is depot level maintenance or activities that directly support that function.

The third assumption that no factors other than activity levels and pollution prevention efforts affect the quantity of waste generation is not always realized. Changes in federal and state hazardous waste regulations are an example of a factor that could affect waste generation and disposal independent of activity levels. For example, the Toxic Characteristic Leaching Procedure (TCLP) implemented in 1990 to determine if a waste is hazardous caused many waste streams that were previously not regulated as hazardous to be considered a hazardous waste. This assumption is, however, a necessary assumption in any measure of waste reduction progress.

The final assumption that waste disposal and activity measures are consistent over time is also a necessary assumption. The data utilized in this research is consistent with respect to the units and procedures used to report the data.

The advantage of using the activity indexing method is that it accounts for changes in hazardous waste disposal that are attributable to changes in production activity. The disadvantages of using this method are that it is somewhat more complicated to calculate and it requires more intensive data collection.

Regression Modeling Method. This technique allows for the development of a prediction of the mean value of some variable of interest based on a given value of an independent variable. It is important to note that "no matter how strong the statistical relationship, no cause-and-effect pattern is necessarily implied by the regression model" (Neter et al., 1989:29). It is logical however, in this situation, to infer that aircraft related maintenance, such as paint stripping, painting, plating, degreasing, etc., generates hazardous waste for disposal. Thus, a cause and effect relationship between the two is a reasonable inference.

In this case, hazardous waste disposal is the dependent variable, and the production activity measures are the independent variables for the regression analyses. The model prediction is then used to compute an adjusted quantity change in a manner similar to the activity indexing method.

The regression analysis yields an equation which can be used to provide a prediction of the amount of hazardous waste disposal for a known or given level of activity. The regression equation is described as follows:

$$Y = B_0 + B_1 * x$$

where

Y = dependent variable (hazardous waste disposal)

B_0 = the y- intercept

B_1 = the slope of the regression line

x = independent variable (level of activity)

The regression line can also be fitted through the origin. In this case, the y-intercept term becomes zero and thus drops out of the equation.

Again, consider the data from Table 2 as an example to demonstrate the least squares linear regression method. The data for the years 1985-1989 listed in Table 2 was used to develop a regression equation which was fitted through the origin. The regression equation fitted through the origin obtained from the data in Table 2 for the years 1985 to 1989 is as follows:

$$HW = 0.214 * DPAHs$$

A predicted value of the hazardous waste disposal for 1992's DPAHs of 3,650,000 was then calculated by applying the regression equation, resulting in a prediction of 781 tons of hazardous waste for disposal. The percent change from this prediction was:

$$\frac{(720-781)}{781} * 100 = -7.8\%$$

Figure 1 displays the scatter plot of the data with the regression line fitted through the origin shown as a dashed line. The coefficient of determination, or r^2, is the proportion of variation in the dependent variable (hazardous waste disposal) that can be explained by the linear regression model (Devore, 1991: 467-468). For instance, an r^2 of 0.90 indicates that 90 percent of the variation in hazardous waste disposal can be attributed to the approximate linear relationship between hazardous waste disposal and DPAHs. In the case of the regression line fitted through the origin for the hypothetical ALC, the coefficient of determination was 0.9660. This indicates that 96 percent of the variation can be attributed to the approximate linear relationship between the two variables.

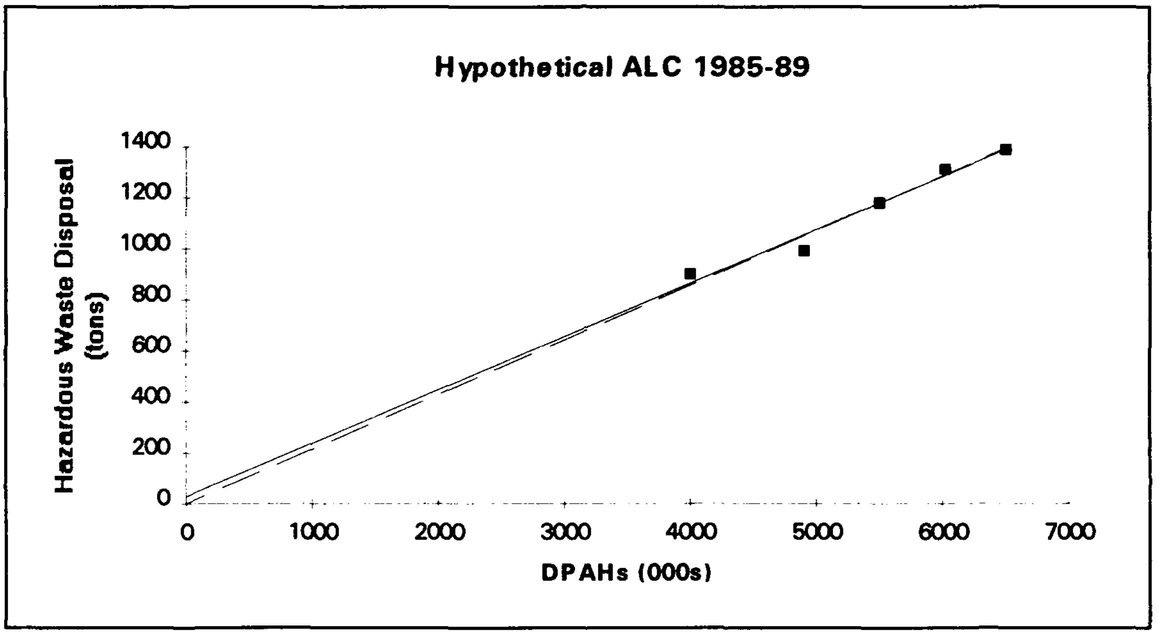

Figure 1. HW Disposal vs. DPAHs 1985-89 for a Hypothetical ALC

The solid line shown in Figure 1 represents the linear regression line with the y-intercept fitted. The equation for this line was:

$$HW = 0.209 * DPAHs + 29.3$$

This line yielded an r^2 of 0.9667. The regression line with the y-intercept fitted provided a better fit to the data and it illustrates that there was a baseline level of hazardous waste generated that was not related to DPAHs. The y-intercept of 29 tons indicates that 29 tons of hazardous waste would be generated if no aircraft maintenance activities were performed.

Additionally, multi-variable regression can be used to predict the amount of hazardous wastes disposal based on several activity variables. As the name implies, a multi-variable regression model uses several independent or x variables to develop the regression equation. This method provides a better fit of the regression line; however, the standard errors associated with each of the independent variables increases the overall error associated with the prediction of the dependent variable.

The advantages of using the multi-variable regression method are that changes in hazardous waste disposal that are attributable to changes in production activity are accounted for, it provides a measure of the strength of the model (coefficient of determination), and it provides a graphical presentation of the relationship. The disadvantage of this method is that it requires an understanding of regression analysis, as well as the availability and understanding of the computer software used to generate the analysis.

III. Research Methodology

This section of the thesis discusses the data requirements, as well as the methodology that will be used to answer the research questions posed in Chapter I.

The primary objective of the research effort was to devise a method of measuring pollution prevention impacts on hazardous waste disposal that adjusts for changing activity levels. This was accomplished by comparing several alternative methods of measuring waste reduction progress at the ALCs by analyzing historical data. The methods that were compared include the actual quantity change, activity indexing, and least squares regression modeling. This comparative analysis also provided the insight to answers to the other research questions. The actual quantity change and activity indexing methods were chosen because they are commonly used measures of pollution prevention effectiveness. The use of least squares curve fitting of historical data to measure waste reduction progress was the author's approach to solving the problem.

Data Collection

This section outlines the data collection activities that occurred during the course of the research effort. Due to the sensitive nature of the hazardous waste disposal data, HQ AFMC requested that the identity of the individual bases involved in the study not be disclosed. To maintain this confidentiality, code numbers were assigned to each of the ALCs involved in the study. The code numbers assigned to the individual locations were recorded by the author, but do not appear in this text. For the purposes of the analysis, AGMC was treated the same as an ALC location and was assigned one of the ALC codes. Thus, the six locations were coded ALCs 1-6.

Hazardous Waste Disposal Data. AFMC's Environmental Management Division (HQ AFMC/CEV) provided data on the amount of hazardous waste generated at the individual ALCs from 1985 to 1993. This data is expressed as tons of hazardous waste generated or disposed of for any given year. This hazardous waste data was provided for CY 1985 to CY 1992 and quarterly for CY 1993. This hazardous waste disposal data is presented in appendix A for reference purposes.

Production Activity Data. HQ AFMC Directorate of Logistics furnished information concerning the levels of aircraft related maintenance performed at the five ALC's and AGMC. Numerous measures of maintenance activity were readily available including: Direct Product Actual Hours (DPAHs), and the number of aircraft, engines, exchangeable aircraft components (exchangeables), and missiles serviced during a given year at the individual ALCs. DPAHs were also provided on a quarterly reporting basis for the fiscal year

1993. DPAHs are an indication of the number of man-hours dedicated to aircraft maintenance at a given ALC. This data is also presented in Appendix A for reference purposes.

This aircraft related maintenance activity data was collected and reported in terms of fiscal years. As a result, there was a lag of ninety days built into the data set. This takes into account the fact that waste generated by activity on a given date has ninety days to be transferred from a HW accumulation point to the hazardous waste storage facility prior to off-site disposal.

Another potential contributor to the overall amount of hazardous waste generated may be the number of active CERCLA removal and remedial actions at a given base during a year. Oftentimes, actions taken under the IRP (Installation Restoration Program) result in the generation of large quantities of hazardous wastes requiring treatment and disposal. Although HQ AFMC/CEV provided historical data concerning the number of such actions taking place from 1985 to 1993, it was later indicated that waste associated with IRP sites is not included in the hazardous waste disposal numbers provided. As a result, IRP activities were not considered in this research.

Analytical Tools

Correlation. The sample correlation coefficient (r) is a measure of how strongly related two variables are in a given sample (Devore, 1991:487). If large values of one variable is related to large values of the other variable, the r-value will be positive. Conversely, if large values of one variable are paired with small values of the second variable, the r-value will be negative. The value of r will always lie between -1 and 1 depending on how strong the two variables are associated with one another, and whether the relationship is positive or negative (Devore, 1991:488). Correlation between two variables can be described as being strong, moderate, or weak depending on the magnitude of r. Devore states that "A reasonable rule of thumb is to say that the correlation is weak if $0 \leq |r| \leq .5$, strong if $.8 \leq |r| \leq 1$, and moderate otherwise" (Devore, 1991: 489). This criteria will be used to describe the strength of the association between the various activity levels and the amount of hazardous waste disposal.

Box and Whisker Plot. The box and whisker plot provides a convenient graphical means to compare the variability and central tendencies of two or more data sets. From the box plot, a data set's median, spread, skew, and any outliers can be readily identified (Devore, 1991:27-28). The structure of the box and whisker plot output from the analytical software Statistix is described in its users manual (Statistix 1992:96-97). It describes the box plot as consisting of a box around the middle half of the data (between the first and third quartiles), with a line located through the box at the median value. Quartiles separate a data set into fourths by rank order, with the second quartile being equal to the median value, and the first quartile separating the lower 25 percent of the data from the upper 75% (Devore, 1991:18). The two lines at the top and bottom of the box are known as the whiskers. The whiskers are determined by calculating the fourth spread of the data set. To calculate the fourth spread, the median of the lower half of the data set and the median of the upper half of the data set must be determined. The fourth spread is defined as the upper fourth minus the lower fourth and is resistant to the presence of outliers (Devore, 1991:28). An outlier is defined by Devore as a data point that lies unusually far from the main body of the data (Devore, 1991:27). The length of whiskers are defined as 1.5 times the value of the fourth spread. These whiskers indicate the range of data values not including any outliers. Outliers are indicated by a circle for extreme outliers and an asterisk for mild outliers. An extreme outlier falls more than 3 times the fourth spread from the middle half of the data. A mild outlier falls between 1.5 times and 3 times the fourth spread from the middle half of the data.

Figure 2 is a box plot of the percent change in hazardous waste disposal from the 1987 baseline for all of the ALCs including AGMC for the years 1990-92. Thus, there were 18 observations in the data set used to create the box plot.

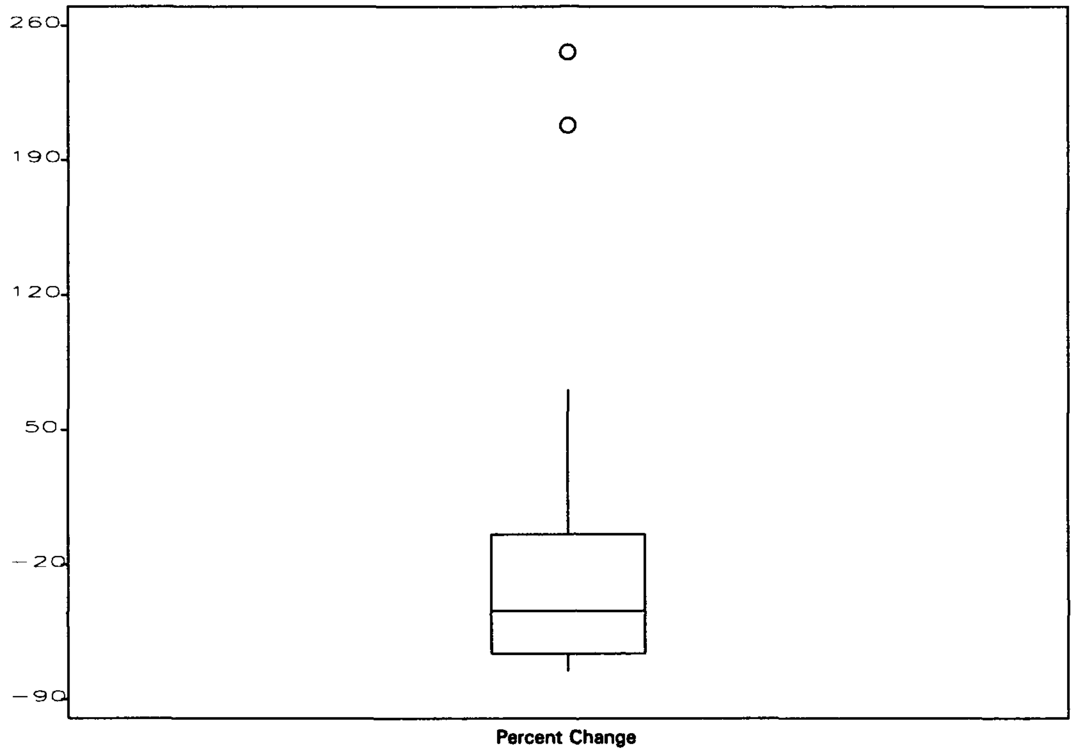

Figure 2. Box and Whisker Plot of the Percent Change in Hazardous Waste Disposal from the 1987 Baseline

The box plot shows that the median value is approximately -50%, and that the middle 50% of the data is slightly skewed toward the bottom of the plot because the median value is located near the bottom of the box. The lower 25% of the data is not very spread out as indicated by the extremely small tail. The upper 25% of the data, on the other hand is rather spread out as evidenced by the relatively long tail and the two probable outliers identified by the two circles at 200 and 240.

General Methodology

This section outlines the methods that were followed to determine if there was a statistical association between the level of the activity variables and the amount of hazardous waste disposal at the individual logistic centers and AGMC. The correlation coefficients were calculated for the 1985 through 1989 yearly data points. Each individual ALC's hazardous waste disposal data was correlated to each of the applicable activity variables. Some of the activity variables are not applicable to certain ALCs. For example only ALC-1 conducts missile maintenance, and therefore missiles could not be correlated to HW disposal for ALCs 2-6. Similarly, only two of the ALCs perform maintenance on aircraft engines. A moderate to strong positive correlation coefficient indicated a significant association between the amount of hazardous waste disposal at an installation and the activity variable in question.

The 1985 to 1989 data points were chosen to establish the relationships between hazardous waste disposal and the various activity variables for two predominant reasons. First, this time period is prior to the promulgation of the Pollution Prevention Act and AFP 19-4. Therefore, the effects of the many process modifications and substitutions that resulted from base wide pollution prevention surveys subsequent to 1990 at the ALCs will not affect the relationships. Second, this will avoid incorporating any waste reduction effects of the hazardous material pharmacies at the ALCs into the correlation.

Additionally, to illustrate the trend of decreasing hazardous waste disposal in association with decreasing activity levels, a time series plot of the most strongly correlated activity variable and the hazardous waste data was developed for the time period 1985 to 1992. A scatter plot of the 1985 to 1989 data for each of the individual ALCs most highly correlated activity variable vs. hazardous waste disposal was also shown to graphically illustrate the nature and intensity of the correlations.

To compare the alternative methods of measuring pollution prevention progress, several iterative comparative analyses were performed. The percent change (current Air Force approach), activity index, and regression modeling methods were compared as applied to the 1990-1993 data. The percent change method was determined by using 1987 as the baseline year. The activity index method was applied by using a single year (1987) as the baseline and also by using the average activity levels for the years 1985-89 as the baseline. Two regression lines were determined for each ALC in each of the analyses. A regression line with the y-intercept fitted and a regression line which was fitted through the origin was determined to predict the amount of hazardous waste disposal for a given level of activity. Again, the data points from 1985-89 were used to develop these regression equations. The regression equations and associated coefficients of determination are included in Appendix B.

The criteria for establishing the best method included: consistency in adjusting for changes in activity levels, realistic and representative predictions for HW disposal based on the activity levels, and operational simplicity. The analytical results, descriptive statistics, and box plots for each of the methods were compared for each of the separate analyses to determine the first two criteria, and operational simplicity was determined qualitatively.

Analysis Based on the Most Highly Correlated Activity Variables. The activity indexing and regression modeling methods were applied first by using the most highly correlated activity variable for each of the individual ALCs as the predictor. For example, for ALC-1, the number of aircraft serviced proved to have the highest correlation with hazardous waste disposal. For ALC-2, the number of exchangeable components processed showed the highest correlation. Thus, aircraft was used as the predictor for ALC-1 and exchangeables was used as the predictor for ALC-2 for determining the activity index and the regression equations.

Analysis Based on DPAHs. A similar analysis was then repeated using the activity variable, DPAHs, which was common to all of the ALCs as the predictor. In this case, the DPAHs for each ALC in 1987 was used as the baseline for the activity index method, and the average DPAHs for 1985-89 was used as the baseline for the average activity index method. The two regression equations for each ALC was determined using the 1985-89 data points for that respective ALC.

Multi-variable Regression Analysis. This analysis developed the two regression equations for each ALC by using all of the applicable activity variables for that respective location. These regression models were again developed using the 1985-89 data points and were applied to the 1990-92 data to make predictions. The predictions were then used to determine the percent change for the regression methods. These values were then compared to the percent change method (current Air Force method) and the average activity index method using the most highly correlated variable.

Proposed Metric Applied to the 1993 Quarterly Data. Finally, as an expanded study, a proposed metric based on the previous analysis was applied to the 1993 quarterly data. The results of applying the average activity index method and the regression model fitted through the origin based on the 1985-89 DPAHs to the 1993 quarterly data were compared to the most current Air Force metric. The current metric uses the 1992 hazardous waste disposal data as the baseline for the percent change method. The metric targets a 50 percent reduction in hazardous waste disposal by CY1999 from the 1992 baseline. The proposed metric uses the average relationship between hazardous waste disposal to the DPAHs for the period prior to the promulgation of the Pollution Prevention Act and AFP 19-4 (1985-89 data) as the baseline.

IV. Data Analysis and Presentation

Establishing the Relationship - Correlation Analysis

Table 3 provides a summary of the analysis of the correlation between hazardous waste disposal and the various maintenance activity variables. A dash in a column indicates that the particular ALC in that row does not perform that maintenance function. For example, ALC-3 does not perform service work on aircraft engines. The correlation coefficients indicate that all of the bases with the exception of ALC-5 had a positive association between the various activity levels and hazardous waste disposal for the 1985-1989 data points. It was not surprising to see the strong correlation of HW disposal to the number of aircraft serviced at ALC-1 and ALC-3. Aircraft maintenance often involves painting and de-painting processes which generate large quantities of HW.

TABLE 3

CORRELATION COEFFICIENTS FOR THE LISTED ACTIVITY VARIABLES TO HW DISPOSAL

(Yearly Data 1985-1989)

Center	DPAHs	Aircraft	Engines	Exchangeables	Missiles
ALC-1	0.8068	0.9286	-	0.6669	0.6493
ALC-2	0.6880	0.7125	0.6285	0.7749	-
ALC-3	0.8860	0.9847	-	0.9582	-
ALC-4	0.5695	-	-	0.7311	-
ALC-5	-0.8783	-0.6376	-	-0.9019	-
ALC-6	0.4691	0.2909	0.5685	0.4919	-

ALC-1. The number of aircraft serviced was the variable that showed the highest correlation for ALC-1. The correlation coefficient (r) of 0.9286 indicates a strong association between hazardous waste disposal and the number of aircraft undergoing Programmed Depot Maintenance (PDM). Figure 3 depicts this relationship graphically for the years 1985-1992. The variables were shown on separate Y-axis scales so that incremental changes in aircraft serviced would not be dwarfed by corresponding incremental changes in HW disposal. Otherwise, if the variables were shown on the same scale, the aircraft service data would all be below the first tick on the HW disposal scale and the ensuing trend would not be apparent. The figure shows a clear long term trend from 1985-1989 of steadily decreasing levels of both hazardous waste disposal and the number of aircraft serviced.

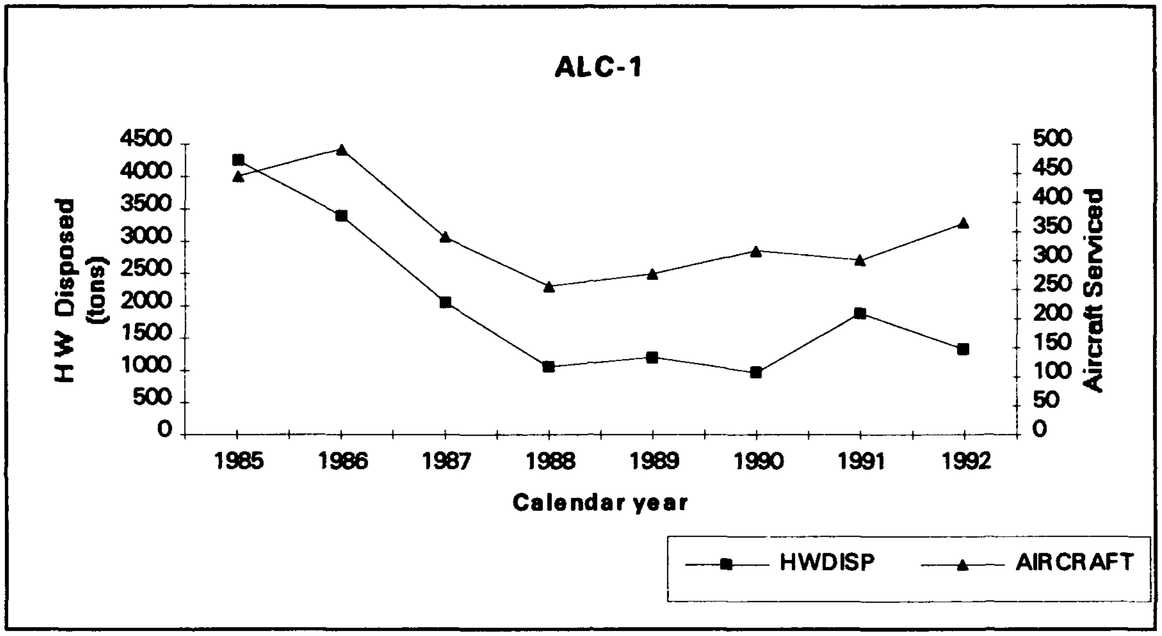

Figure 3. HW Disposal and Number of Aircraft Serviced at ALC-1

The scatter plot depicted in figure 4 shows the fitted regression line for the five data points. The coefficient of determination (r^2) for this line is 0.8623 which suggests that 86 percent of the variation in HW disposal is attributable to changes in the number of aircraft serviced.

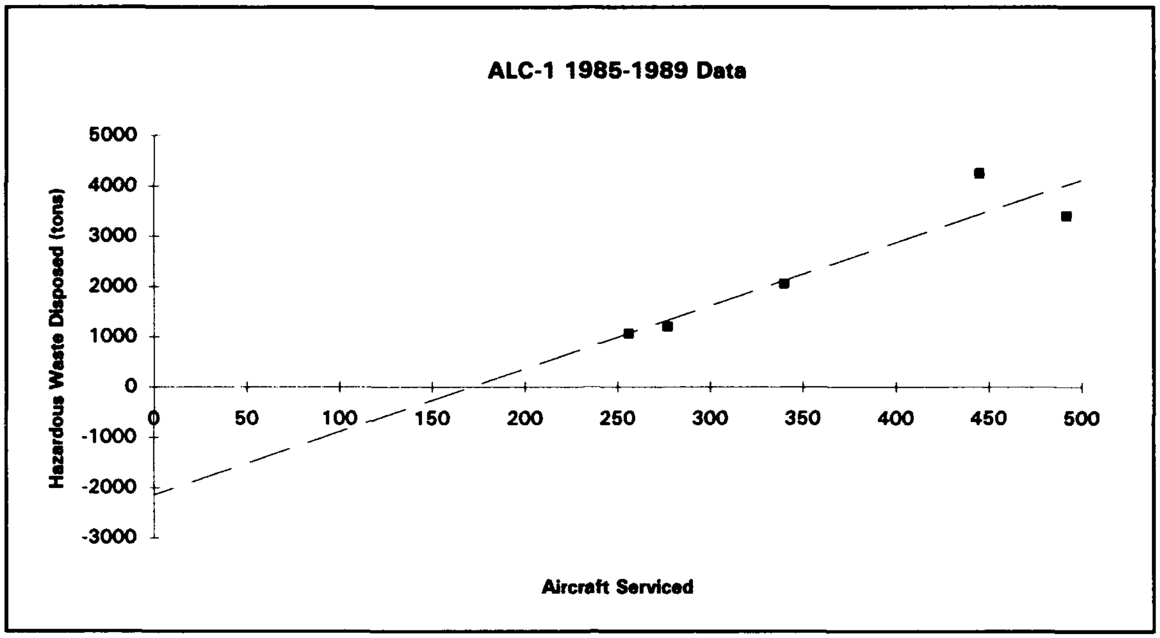

Figure 4. Scatter Plot of HW Disposal vs. Aircraft at ALC-1

DPAHs also had strong correlation with hazardous waste disposal. The number of exchangeables and number of missiles serviced both had moderate correlations with hazardous waste disposal for ALC-1.

<u>ALC-2</u>. The number of exchangeables for ALC-2 proved to have the highest r-value (0.7749). This indicates a moderate association between the two variables by definition; however, this value is very close to the 0.8 value required for strong correlation. Figure 5 depicts the levels of hazardous waste disposal and number of exchangeables processed at ALC-2 for the years 1985-1992. The figure depicts the trend of decreased hazardous waste

disposal and the number of exchangeables processed from 1985-1989.

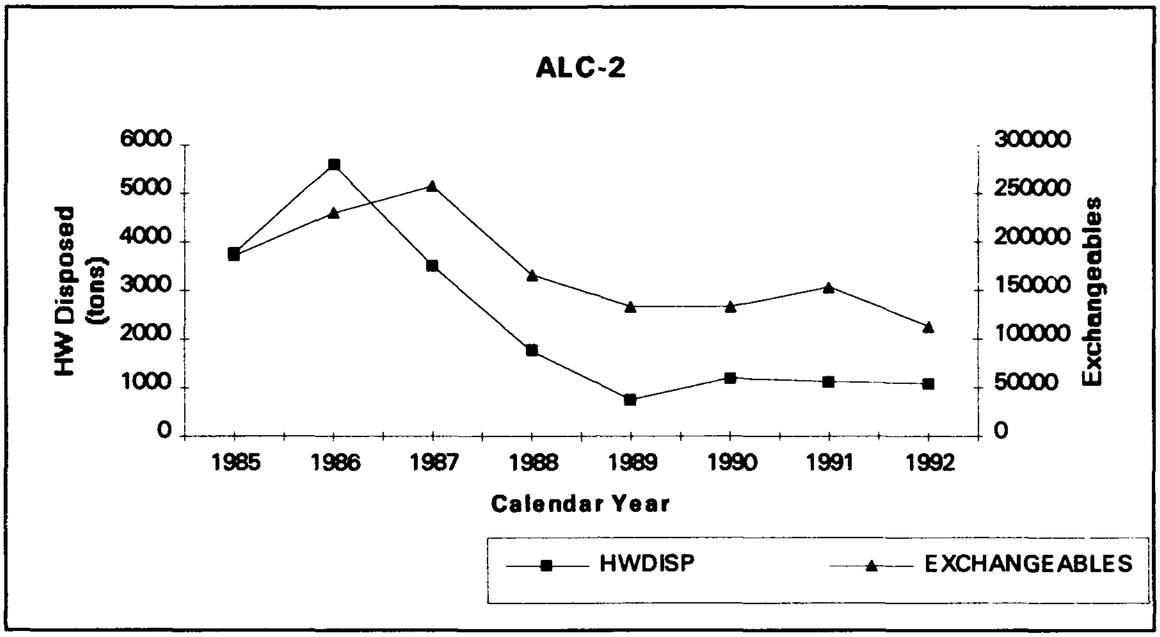

Figure 5. HW Disposal and Number of Exchangeables at ALC-2

Figure 6 further supports this positive relationship in the scatter plot. The fitted regression line in this case had an r^2 of 0.6005. This lower r^2 is apparent from the figure because the data points appear to be more scattered about the line than in the corresponding figure for ALC-1.

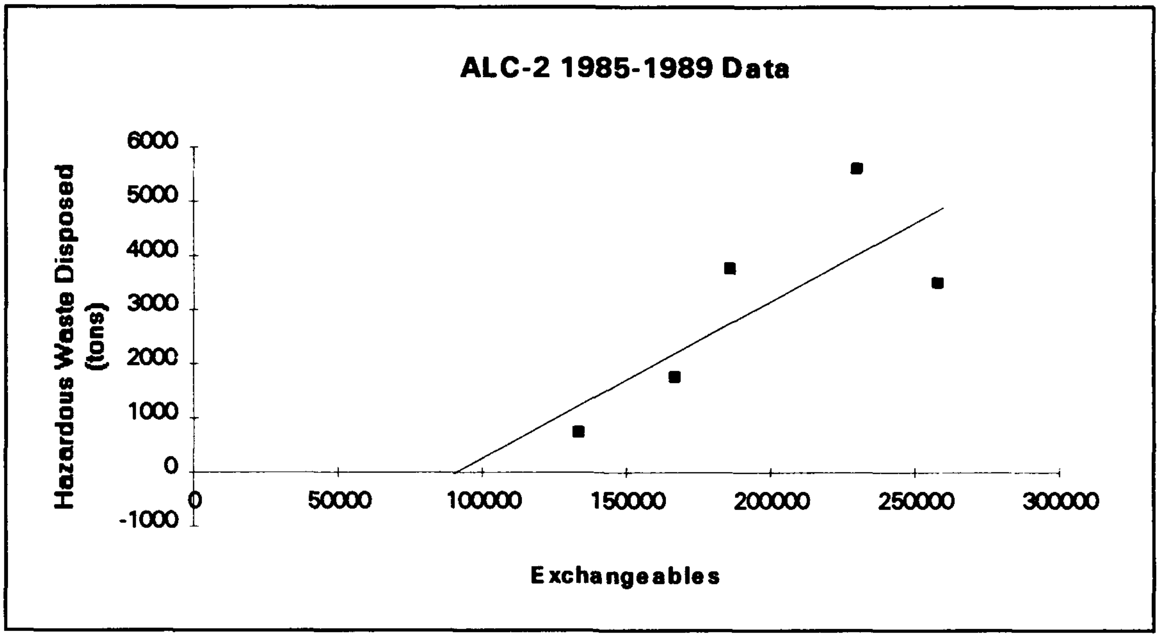

Figure 6. Scatter Plot of HW Disposal vs. Exchangeables at ALC-2

DPAHs, the number of aircraft serviced, and the number of engines serviced also had moderate correlation with the amount of hazardous waste disposed of at ALC-2.

ALC-3. For ALC-3, the number of aircraft serviced had the highest correlation with hazardous waste disposal between 1985 and 1989. The r-value of 0.9847 indicates an extremely strong positive correlation between the two variables. Figure 7 supports the relationship by showing a trend of decreased hazardous waste disposal coupled with decreased number of aircraft serviced over time.

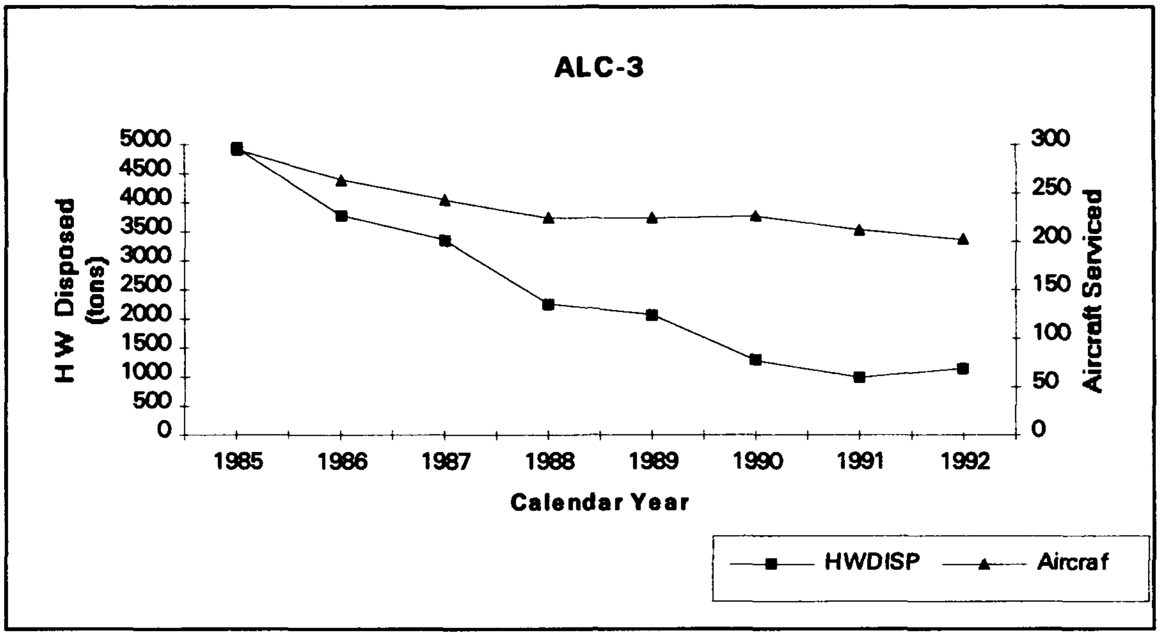

Figure 7. HW Disposal and Number of Aircraft Serviced at ALC-3

The scatter plot shown in Figure 8 illustrates the strength of this association. The fitted regression line had an r^2 value of 0.9697. This indicates an extremely good fit of the data points to the line for real world data.

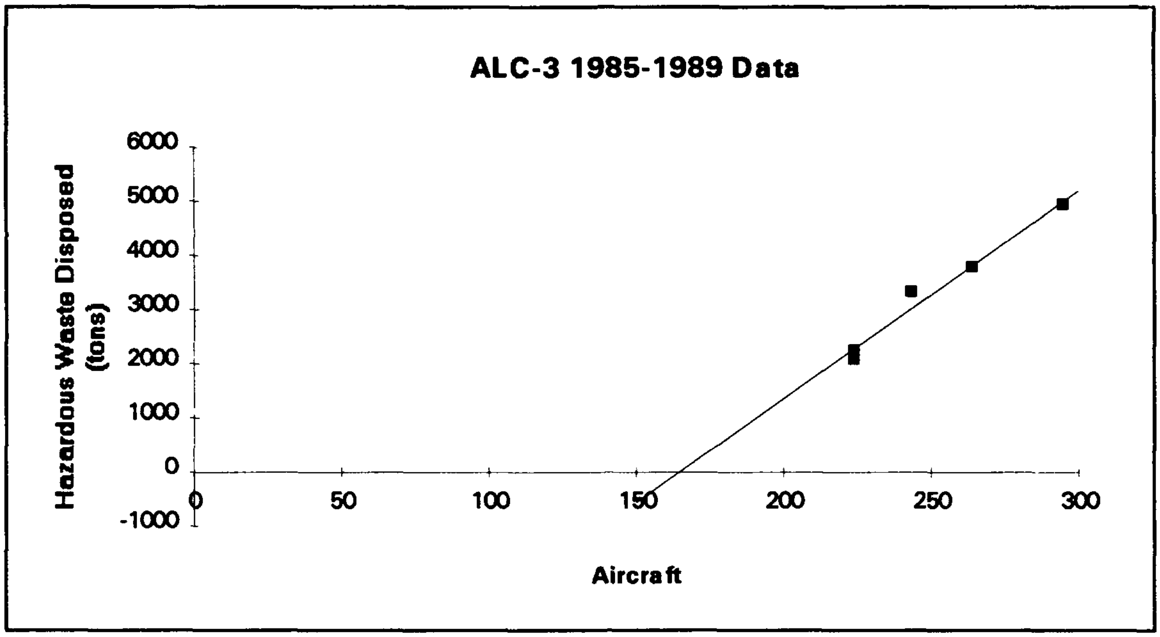

Figure 8. Scatter Plot of HW Disposal vs. Aircraft at ALC-3

DPAHs, and the number of exchangeables processed also had strong correlation with hazardous waste disposed during the period of 1985-1989.

ALC-4. The number of exchangeables processed had the highest correlation with hazardous waste disposal for ALC-4. The r-value of 0.7311 indicates a moderate association between the two variables. Figure 9 depicts this relationship graphically and shows the long term trend of decreased hazardous waste disposal coupled with decreased number of exchangeables.

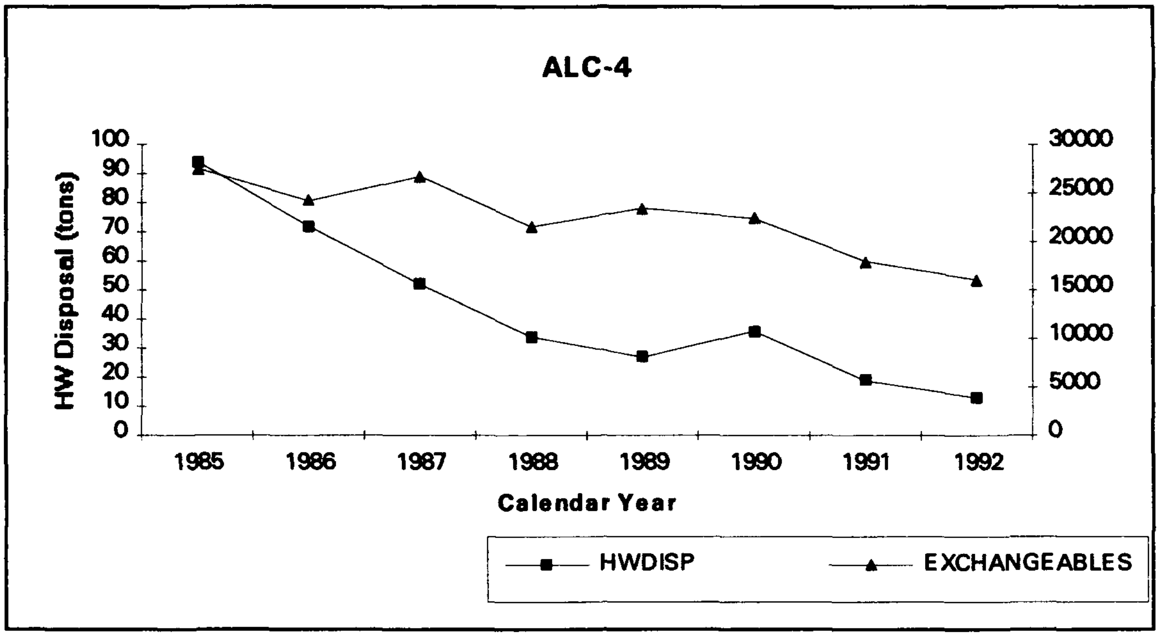

Figure 9. HW Disposal and Number of Exchangeables at ALC-4

The scatter plot of the 1985-1989 data (Figure 10) illustrates the nature and strength of this association graphically. In this case, the data points appear to be more spread out from the line than in the other scatter plots. This is apparent in the relatively low r^2 value of 0.5346 of the fitted regression equation. For this model, only 53 percent of the variation in HW disposal was attributable to changes in the number of exchangeable parts processed.

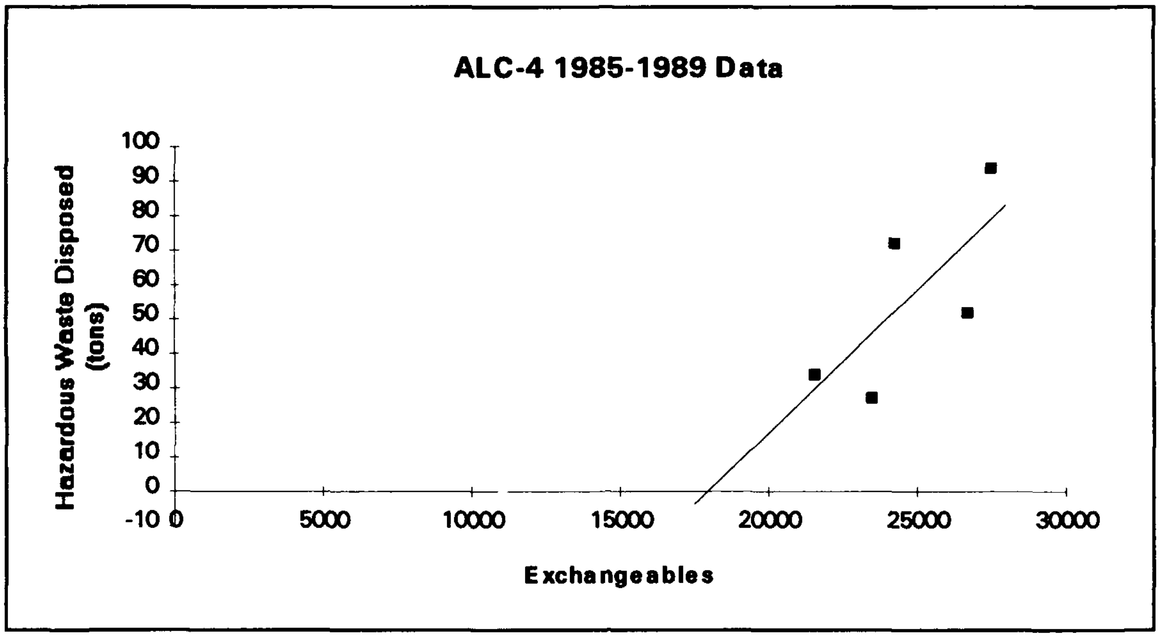

Figure 10. Scatter Plot of HW Disposal vs. Exchangeables at ALC-4

DPAHs also had a moderate correlation with the amount of hazardous waste disposed at ALC-4 for the 1985-1989 time period.

ALC-5. None of the activity variables had a positive correlation with hazardous waste disposal for ALC-5 for the time period 1985-1989. The relationship proved to be the opposite of the other ALCs. The number of exchangeables had strong negative correlation, and DPAHs and the number of aircraft serviced both had moderate negative correlations. This negative correlation suggests that decreases in maintenance activity leads to increased hazardous waste disposal at ALC-5. This suggestion defies logic and is counter to the hypothesis that HW disposal and depot maintenance activity levels are positively correlated. Investigation into this phenomenon revealed that during the period from 1986-1988, significant additional waste streams were identified as hazardous waste. Also, in 1990, the implementation of the TCLP rule resulted in the disposal of several previously unregulated wastes. The large increase in HW disposal apparent in 1991 was the result of the disposal of 635 tons of industrial waste treatment plant sludge. Prior to 1991, no IWTP sludge was disposed of from ALC-5.

Figure 11 is a time series plot of the data from 1985-1992 that depicts the relationship between the number of exchangeables processed and the amount of hazardous waste disposed at ALC-5. Again, the trend was increased amounts of hazardous waste associated with decreases in the number of exchangeable parts processed.

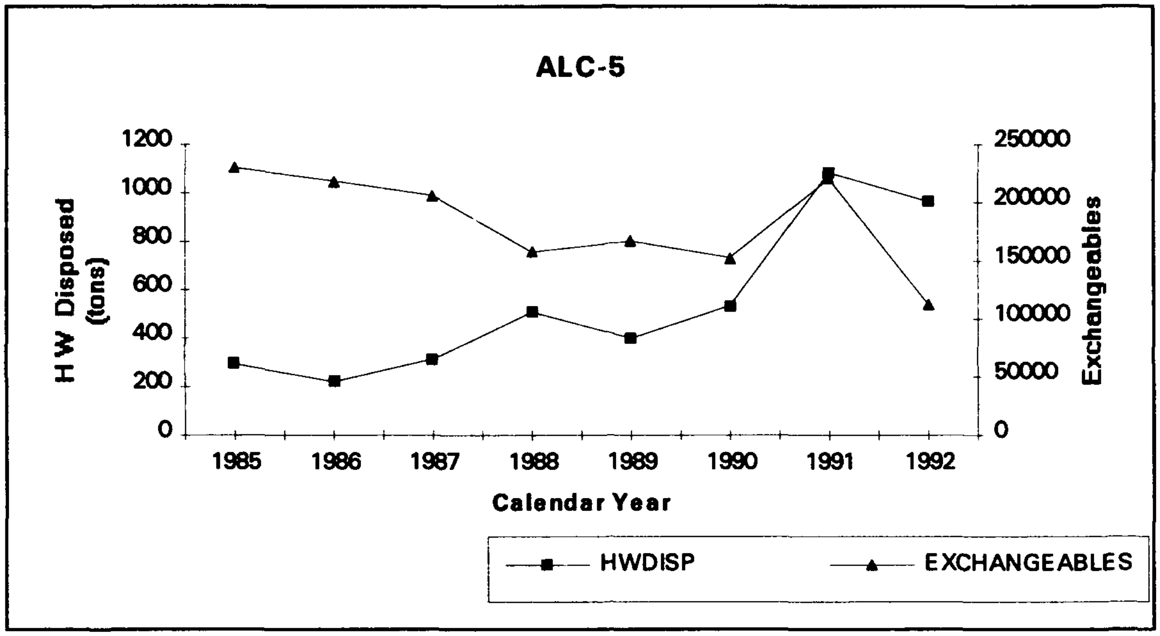

Figure 11. HW Disposal and Number of Exchangeables at ALC-5

The scatter plot of the 1985-1989 data (Figure 12) illustrates the negative slope of the fitted regression line. The r^2 for this equation was 0.8134 which indicates a fairy good fit of the data to the line; however, the slope of the line was negative.

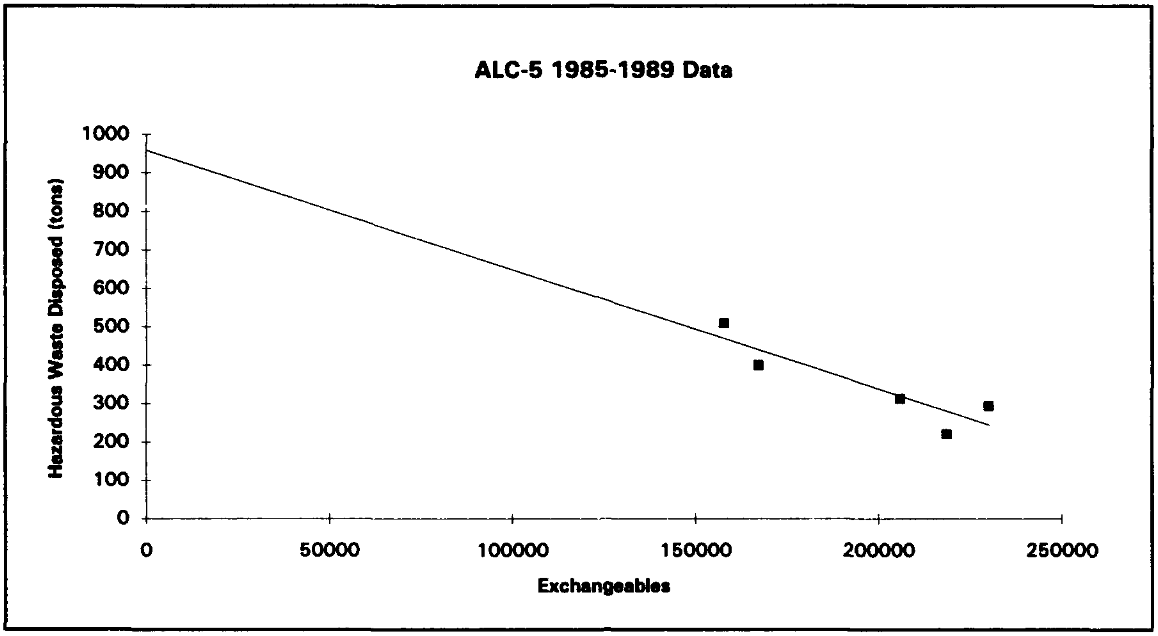

Figure 12. Scatter Plot of Exchangeables vs. HW Disposal at ALC-5

Because the data was inconsistent with the other five ALCs, and that the relationship was totally opposite of the other five ALCs, the application of the alternative methods was not conducted on the data for ALC-5.

ALC-6. The number of engines serviced had the highest positive correlation for ALC-6. The r-value of 0.5685 indicates a moderate correlation between the two variables. This value is close to an r-value of less than 0.5 which would indicate a weak correlation between the two variables.

Figure 13 depicts this association graphically. The figure shows an overall trend of decreased hazardous waste disposal associated with decreases in the number of engines serviced between 1985 and 1989; however, this trend is not as apparent in this case as it is in the figures for ALCs 1-4.

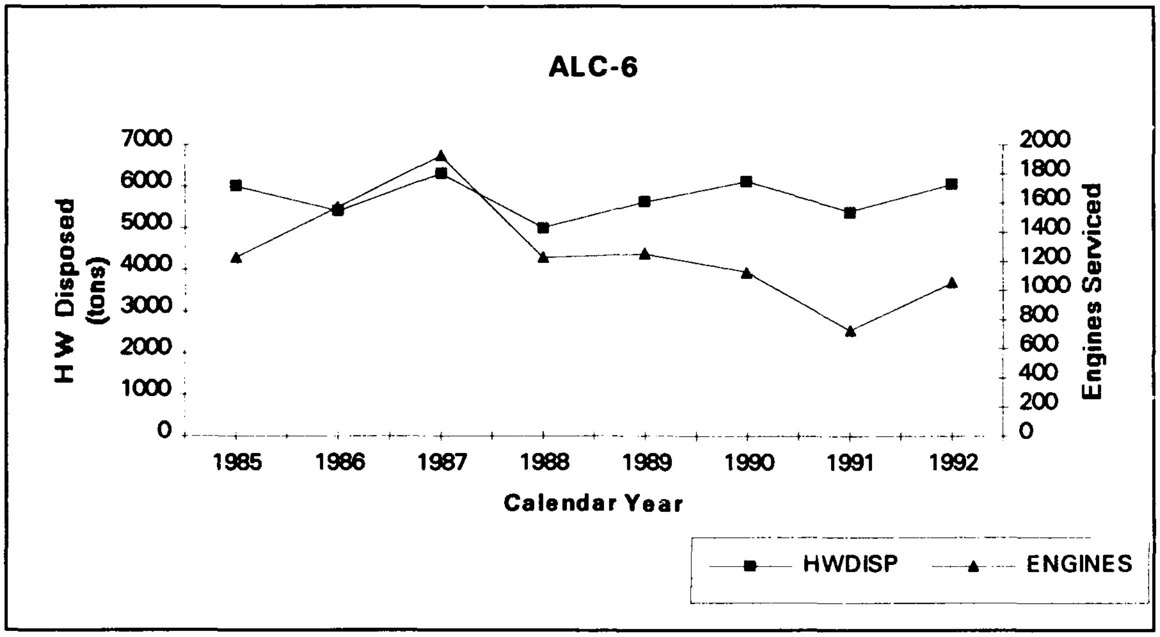

Figure 13. HW Disposal and Number of Engines Serviced at ALC-6

Figure 14 is a scatter plot of the 1985-1989 HW disposal vs. engines serviced for ALC-6. The number of engines serviced is steadily decreasing; however, the expected associated decrease in hazardous waste disposal was not seen. The fitted regression line in this case is nearly a horizontal line with a slight positive slope (r^2=0.3232) and a y-intercept of 4316 tons. This suggests that approximately 4300 tons of HW would be disposed of if no engines were serviced in a given year. The relatively weak r^2 value and the horizontal nature of the regression line is indicative that a large percentage of the hazardous waste disposed of at ALC-6 is independent of the number of engines serviced.

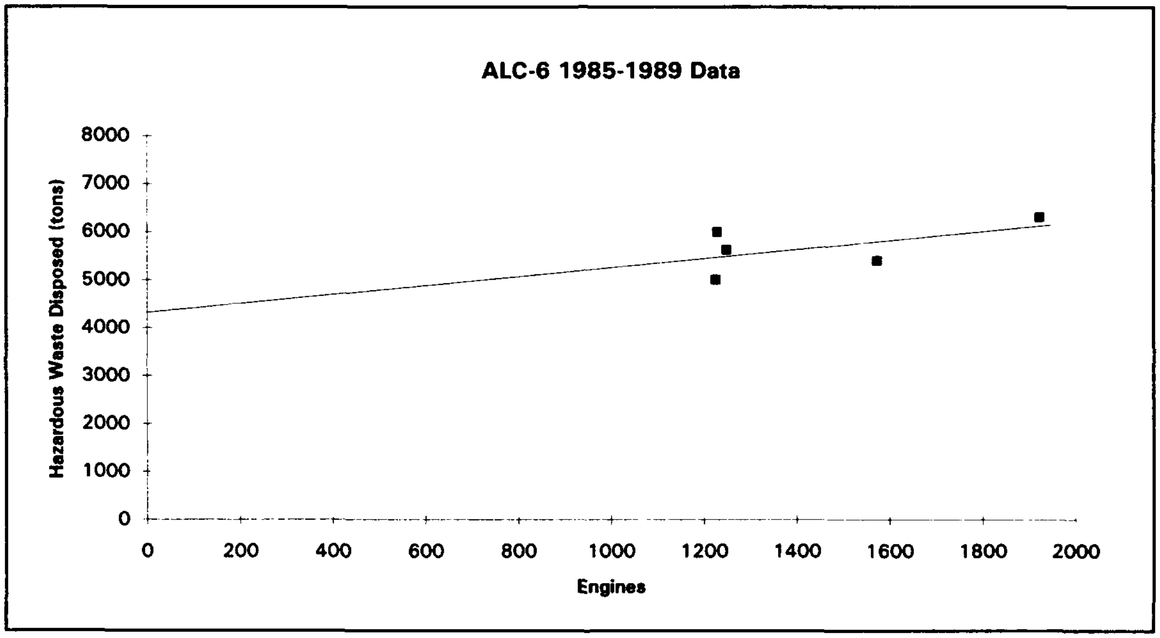

Figure 14. Scatter Plot of HW Disposal vs. Engines Serviced at ALC-6

DPAHs, the number of aircraft, and exchangeables processed all had weak correlation with the amount of hazardous waste disposed between 1985 and 1989 for ALC-6, as indicated in Table 3.

Based on the correlation analysis, it is apparent that there was a positive association between depot maintenance activities and the amount of HW disposal at all but one of the ALCs. This positive correlation was strong to moderate for all activity variables at all but one of the ALCs.

Comparative Analysis of the Alternative Methods

Based on the Most Highly Correlated Activity Variable. The yearly data from 1985-1992 was analyzed in accordance with the methods discussed in Chapter III. In this analysis, the activity variable that had the highest positive correlation to HW disposal for each ALC was used to develop the activity index and regression models for that ALC. For example, the number of aircraft serviced was used for ALC-1 as the predictor, whereas the number of exchangeables processed was used as the predictor for ALC-2 (refer to Table 3 for correlation results). The data from 1985-1989 was used to develop the activity index for 1987, average activity index for 1985-1989, and the two regression models for each individual ALC. These regression equations are listed in Appendix B. A prediction of hazardous waste disposal was then made using the two activity indices and the two regression equations for each ALC based on the appropriate activity variable level for the years 1990-1992 for each respective ALC. The percent change from the predictions was then calculated and compared to the percent change from the 1987 baseline (Air Force Method). ALC-5 data was not analyzed due to the negative correlation results obtained in the previous section.

Table 4 provides a summary of the percent change in hazardous waste generation for the methods. The percent change from the 1987 based activity index prediction resulted in a more conservative number for the reduction of hazardous waste in each case. This is because the level of activity was lower at each base for the years 1990-92 than its respective 1987 activity level. It is more conservative in the respect that the effects of the lower activity levels were factored out of the measurement. The one exception to this occurs for ALC-1 in 1992 when the number of aircraft serviced exceeded the 1987 level which resulted in an activity index of 1.07 (365/340). In this case, the activity index method yielded a higher percent decrease (-40%) in hazardous waste disposal than the percent change method from the 1987 baseline (-35%). Thus, the activity indexing and regression methods compensated for the fact that there was a relative increase in activity at ALC-1 in 1992. This method shows that the effectiveness of ALC-1's pollution prevention efforts were greater than the Air Force metric suggests for the 1992 measurement.

TABLE 4

YEARLY PERCENT CHANGE IN HAZARDOUS WASTE DISPOSAL FOR THE VARIOUS METHODS

ALC	YEAR	FROM 1987 BASELINE	FROM ACTIVITY INDEX PREDICTION (1987 BASED)	FROM ACTIVITY INDEX PREDICTION (1985-89 AVG.)	FROM FITTED REGRESSION PREDICTION	FROM REGRESSION PREDICTION THRU ORIGIN
ALC-1	1990	-53	-50	-54	-47	-56
	1991	-8	4	-5	16	-10
	1992	-35	-40	-45	-45	-48
ALC-2	1990	-66	-34	-43	-6	-45
	1991	-68	-46	-53	-40	-55
	1992	-69	-30	-39	-56	-42
ALC-3	1990	-62	-58	-57	-46	-46
	1991	-70	-65	-64	-45	-55
	1992	-66	-58	-56	-20	-45
ALC-4	1990	-31	-17	-29	-2	-30
	1991	-63	-131	-53	13790	-54
	1992	-75	-58	-64	184	-65
ALC-6	1990	-3	65	38	14	42
	1991	-14	127	89	8	94
	1992	-4	75	46	14	50

Also from Table 4, it can be seen that the percent change based on the average activity level from 1985-1989 did not always result in a lower percent decrease than the current Air Force method. Again, this occurred for ALC-1 where the average activity index for 1985-1989 was greater than one for the years 1990 and 1992. The values for the two activity indexing methods also differed because the average level of hazardous waste disposal over the period from 1985-1989 that was used to compute the prediction often varied from the 1987 amount. This average level of hazardous waste for 1985-1989 was less than the 1987 level for 3 out 5 of the ALCs studied.

The percent change from the two regression analysis provided similar results as the average based activity index method. The regression that was fitted through the origin provides results that were more consistent with the average based activity index method. This was because the regression equation in which the y-intercept was fitted produced an extremely small or negative prediction for hazardous waste disposal for low cases of the independent variable (activity level). Figure 15 illustrates this phenomenon for the regression analysis for ALC-1. The figure shows that a negative amount of hazardous waste is predicted for any number of aircraft below 170. As a result, the prediction from which the percent reduction was calculated was an extremely small value, and in some cases negative.

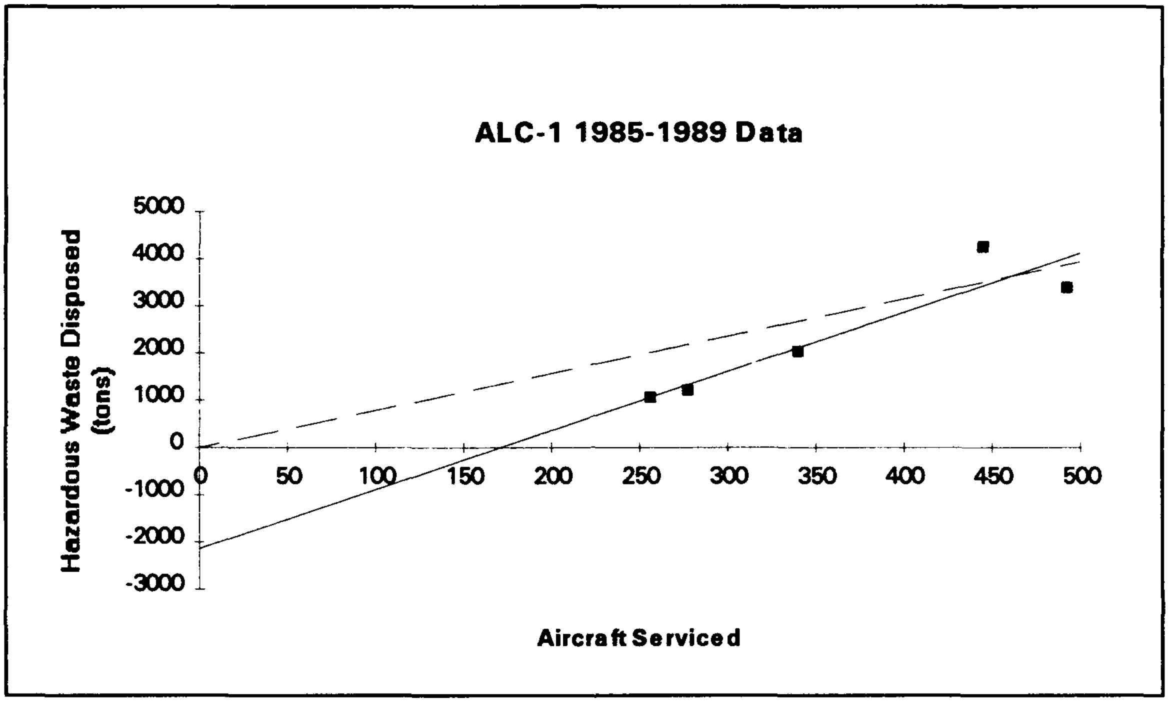

Figure 15. Scatter Plot with Fitted Regression Line for ALC-1, 1985-89 Data

The 1991 regression prediction resulting from the fitted regression equation for ALC-4 illustrates this concept. The fitted regression equation for ALC-4 was as follows:

HW disposal=0.0082888*exchangeables-148.8875

The number of exchangeables processed in 1991 at ALC-4 was 17979 which resulted in a prediction of HW disposal of 0.1368 tons. Because the actual quantity of hazardous waste disposal in 1991 for ALC-4 was 19 tons, a 13790 percent increase from the prediction resulted.

The descriptive statistics shown in Table 5 further support the previous discussion relating to Table 4. The mean percent change in hazardous waste disposal was lower for each of the alternative methods when compared to the current Air Force method. However, the standard deviation for each of the alternative methods is greater, with the fitted regression method's being much greater. This is because the accuracy of the fitted regression method decreases for low levels of activity and therefore does not provide a reasonable prediction.

TABLE 5

DESCRIPTIVE STATISTICS FOR TABLE 4 PERCENT CHANGE DATA

STATISTIC	1987 BASELINE	ACTIVITY INDEX (87 BASED)	ACTIVITY INDEX (85-89 BASED)	FITTED REGRESSION	REGRESSION THRU ORIGIN
MEAN	-45.8	-21.1	-25.9	911.5	-24.3
MEDIAN	-62	-40	-45	-6	-45
STANDARD DEVIATION	27.1	65.1	46.9	3550.2	47.6
MIN.	-75	-131	-64	-56	-65
MAX.	-3	127	89	13743	94

Further study of the data indicated that the results for ALC-6 were outliers in the data set. This is due to the relatively weak r-value of 0.5685 when compared to the r-values for the other bases studied. Also, the other bases showed relatively large reductions in hazardous waste disposal from 1990-92 when compared to their respective 1987 level, whereas ALC-6 did not. Consequently, these outliers tended to severely skew fitted regression method results.

Figure 16 is a box plot of the data for the various methods. The figure shows that all four of the alternative methods' distributions were shifted up on the box plot when compared to the percent change method. The average activity index and the regression fitted through the origin methods provide a more conservative estimate of the percent reduction in hazardous waste disposal during the period in question with less variation in that percent reduction when the outliers are not considered. Consequently, all of the outliers shown on the figure resulted from data points associated with ALC-6. The activity index method based on 1987 activity levels was the most variable of the five methods investigated. This is apparent in the spread of the data based on this method as indicated in the relatively large box and long tails shown in the box plot.

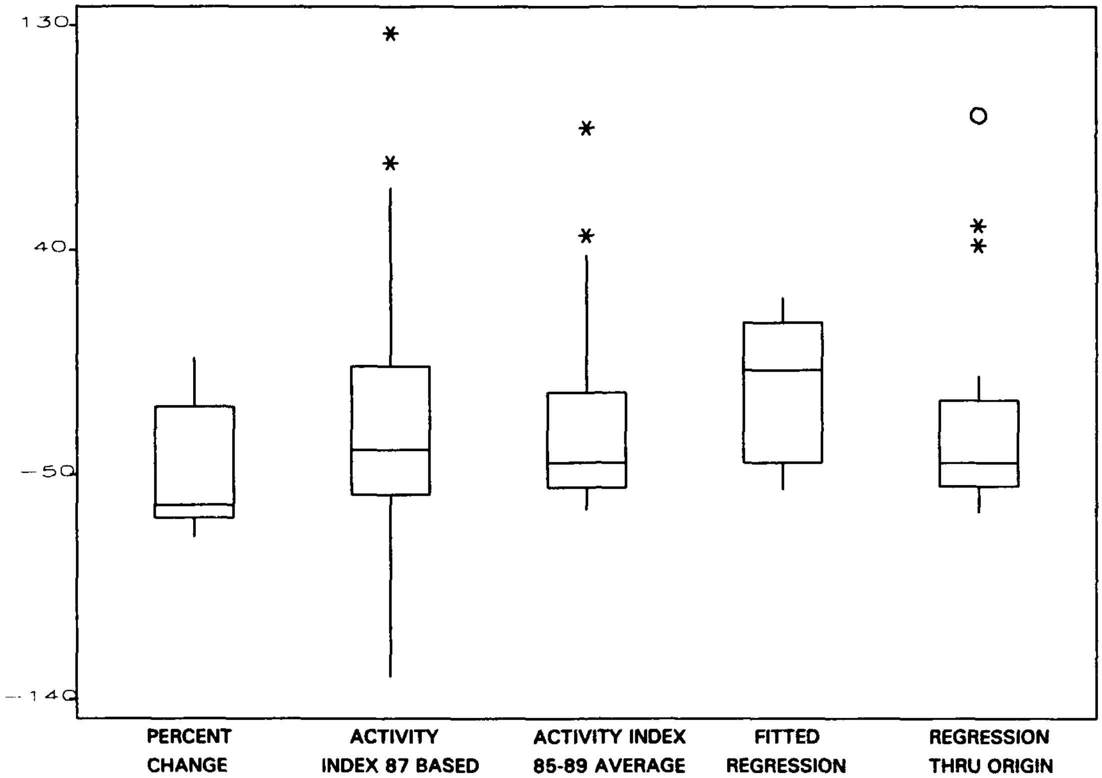

Figure 16. Box and Whisker Plots for the Various Methods Based on Highest Correlated Variables

As discussed in Chapter II, the AFMC goal was to achieve a 50 percent reduction in HW disposal from the 1987 baseline by 1992. Looking at Table 4, it is apparent that ALCs 2, 3, and 4 achieved this goal based on the AFMC metric using the percent change method (-69, -66, and -75 percent, respectively). However, when the 1987 based activity index was used, these values dropped to -30, -58, and -58 percent, respectively. When the 1985-1989 average activity index method was applied, the values decreased to -39,-56, and -64 percent, respectively, relative to the percent change method. When the fitted regression method was applied, these values changed to -56, -20, and 184 percent, respectively, relative to the percent change method. Finally, when the regression through the origin method was applied, these values changed to -42, -45, and -65, respectively. This indicates that significant progress was made toward reducing HW disposal at these locations from the 1987 levels; however, this progress was not as great when the reductions in activity levels were taken into account. The average activity index method and the regression line fitted through the origin provided the desired compensation for changes in activity without being overreactive to those changes.

Analysis Based on DPAHs. The same analysis as performed above was conducted using the total number of hours dedicated to depot level maintenance (DPAHs) as the activity variable. Again, the data from 1985-1989 was used to develop the activity index and regression models. These regression equations are listed in Appendix B.

Table 6 below contains the results of this analysis for the various methods of measuring waste reduction progress. DPAHs were lower for each base in the years 1990-1992 than the DPAHs in 1987. The DPAHs in 1990-1992 were also lower than the average DPAHs for 1985-89 except for ALC-4 in 1990. Therefore, the activity index for each case was less than

1.0 except for the ALC-4 1990 average activity index. As a result, both the activity index method based solely on 1987 levels, and the activity index method based on the 1985-89 average levels indicated that waste reduction was lower for the 1990-92 period than the Air Force metric indicates.

TABLE 6

PERCENT CHANGE IN HAZARDOUS WASTE DISPOSAL FOR THE VARIOUS METHODS

(DPAH BASED)

ALC	YEAR	FROM 1987 BASELINE	FROM ACTIVITY INDEX PREDICTION (1987 BASED)	FROM ACTIVITY INDEX PREDICTION (1985-89 AVG.)	FROM FITTED REGRESSION PREDICTION	FROM REGRESSION PREDICTION THRU ORIGIN
ALC-1	1990	-53	-49	-53	-34	-58
	1991	-8	6	-8	373	-12
	1992	-35	-17	-35	229	-32
ALC-2	1990	-66	-64	-60	-49	-61
	1991	-68	-62	-58	410	-59
	1992	-69	-61	-58	173	-58
ALC-3	1990	-62	-56	-57	-44	-58
	1991	-70	-65	-66	-47	-66
	1992	-66	-57	-59	-18	-59
ALC-4	1990	-31	-29	-34	-25	-35
	1991	-63	-56	-60	190	-60
	1992	-75	-64	-67	115	-67
ALC-6	1990	-3	17	21	14	22
	1991	-14	19	23	7	23
	1992	-4	42	47	22	47

Results similar to those from the analysis based on the most highly correlated activity variable were seen when the DPAHs were used as the independent variable for the developing the regression equations. As seen previously, the regression line fitted through the origin produces results that are consistent with the average activity index method. The results from the regression line with the y-intercept fitted again yielded predictions that were negative or extremely low for the lower levels of the independent variable (DPAHs) due to a negative y-intercept in the regression equations.

Consistent with the previous analysis, descriptive statistics for the various methods were calculated. Table 7 shows that by taking into account the level of maintenance activity, the mean percent reductions in hazardous waste disposal were again consistently lower. Once more, the negative y-intercept resulting from the fitted regression equation severely shifts the mean for this method, as well as increasing its standard deviation.

TABLE 7

DESCRIPTIVE STATISTICS FOR TABLE 6 PERCENT CHANGE DATA

STATISTIC	1987 BASELINE	ACTIVITY INDEX (87 BASED)	ACTIVITY INDEX (85-89 BASED)	FITTED REGRESSION	REGRESSION THRU ORIGIN
MEAN	-45.8	-33.1	-34.9	87.7	-35.5
MEDIAN	-62	-56	-57	14	-58
STANDARD DEVIATION	27.1	36.9	37.4	154.2	37.7
MIN.	-75	-65	-67	-49	-67
MAX.	-3	42	47	410	47

Figure 17, the box plot of the results for the four methods, indicates that the average activity index method and the regression fitted through the origin method result in the least varied data, while still reducing the mean percent reduction to account for the lower levels of activity. The extremely varied data reflected in the fitted regression method was due to the negative predictions resulting for lower levels of activity.

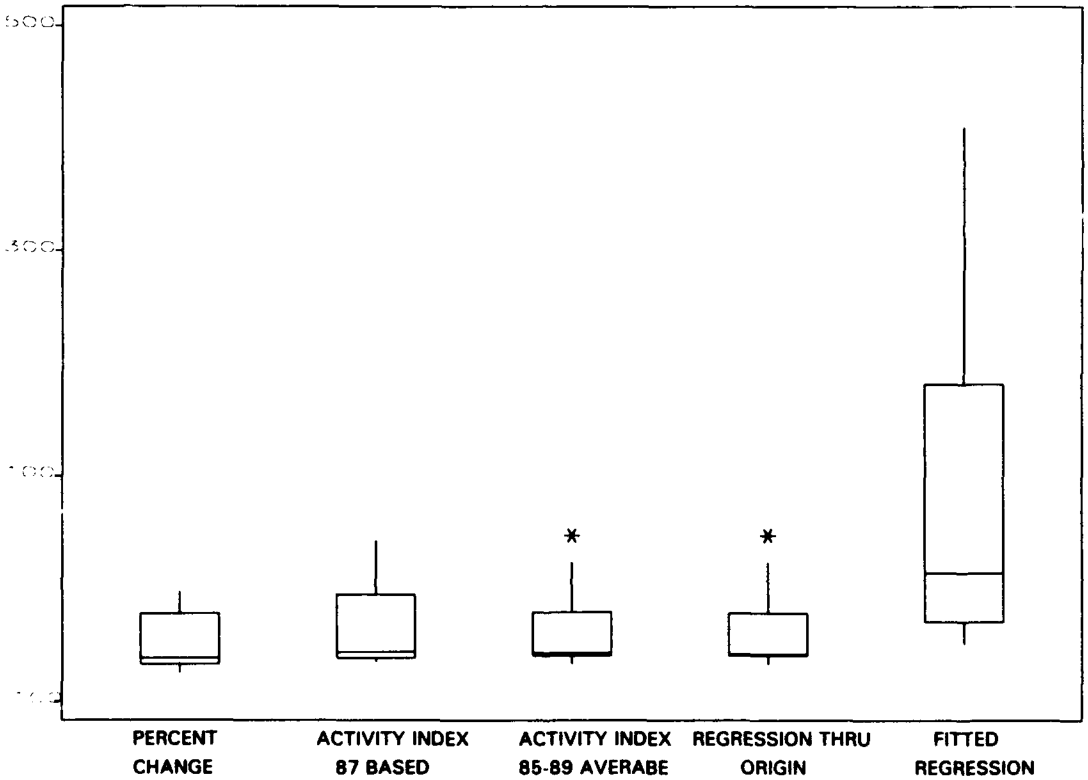

Figure 17. Box and Whisker Plots for the Various Methods Based on DPAHs

A comparison of the results of the alternative methods to the goal of a 50 percent reduction by 1992 indicates that significant progress was achieved, but the progress is not as great when the decreased activity levels were taken into account. Again, ALCs 2, 3 and 4 achieved the desired reduction in 1992, and this reduction was still greater than 50 percent for those centers when the activity index, average activity index, and regression through the origin methods were applied.

Multi-variable Regression Analysis. In this analysis, the two regression equations were developed for each ALC by using all of the applicable variables for each individual ALC. The activity variables are listed in Appendix A. A listing of the regression equations used for the analyses is provided in Appendix B. A prediction was made for 1990-1992 based on these equations, and the percent change from these predictions were calculated for each ALC. The results were then compared to the percent change and average activity index methods for the same years.

The results obtained from the multi-variable regression analysis were similar to the results obtained from the analysis using the most highly correlated activity variable. These results are presented in table 8. The fitted multi-variable regressions line again resulted in negative y-intercepts which caused the low adjusted mean percent change in hazardous waste disposal using this method.

TABLE 8

YEARLY PERCENT CHANGE IN HAZARDOUS WASTE DISPOSAL

MULTI-VARIABLE REGRESSION

ALC	YEAR	FROM FITTED REGRESSION PREDICTION	FROM REGRESSION PREDICTION THRU ORIGIN
ALC-1	1990	-37	-45
	1991	49	7
	1992	-13	-52
ALC-2	1990	7	-18
	1991	27	-57
	1992	-17	-80
ALC-3	1990	-31	-26
	1991	-41	-41
	1992	-1	-1
ALC-4	1990	-14	-16
	1991	12	-34
	1992	63	-58
ALC-6	1990	4	15
	1991	3	28
	1992	2	23

The descriptive statistics shown in table 9 show that the mean percent reduction is lower for the multi-variable regression methods. The regression fitted through the origin again has a larger standard deviation than the multi-variable regression method with the y-intercept fitted.

TABLE 9

DESCRIPTIVE STATISTICS FOR TABLE 8 PERCENT CHANGE DATA

STATISTIC	1987 BASELINE	ACTIVITY INDEX (87 BASED)	ACTIVITY INDEX (85-89 BASED)	FITTED REGRESSION	REGRESSION THRU ORIGIN
MEAN	-45.8	-21.1	-25.9	0.9	-23.7
MEDIAN	-62	-40	-45	2	-26
STANDARD DEVIATION	27.1	65.1	46.9	29.2	32.8
MIN.	-75	-131	-64	-41	-80
MAX.	-3	127	89	63	28

Figure 18 is a box plot of the distributions of the results for the percent change, multi-variable regression through the origin, multi-variable regression, and average activity index methods. This plot indicates that the average activity index method had the least spread in the data, while adjusting the mean to account for the reductions in maintenance activity. The other alternative methods also shift the distribution to account for the reduced maintenance activity, but the spread of the data was clearly increased when compared to the current metric and the average activity index method. The fitted regression severely shifted the distribution upward indicating that even less pollution prevention progress was made relative to 1987 when changes in all of the activity variables were taken into account. It is important to note that the mean for the fitted regression method is skewed by the 1991 and 1992 data points for ALC-4.

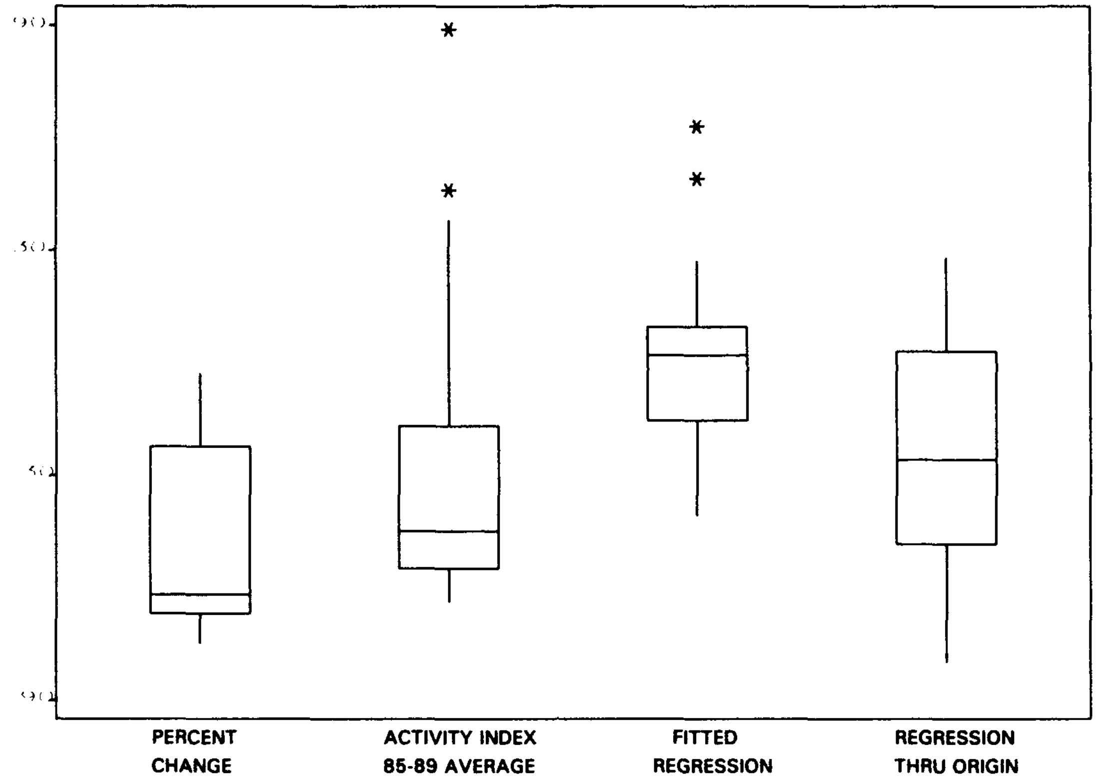

Figure 18. Box and Whisker Plots for the Various Methods for Multi-variable Regressions

<u>Conclusions from the Comparative Analysis</u>. The percent change method clearly provided no means of adjusting for the variations in aircraft related maintenance activity. Due to the strong to moderate correlation between HW disposal and the activity variables, the use of a method that adjusts the measure of pollution prevention for changes in activity levels was justified. The least squares regression equation with the y-intercept fitted was resulted in unrealistic and illogical predictions for the amount of HW disposal. This was due to a negative y-intercept which resulted in a

negative or extremely low prediction for HW disposal based on the activity levels experienced in 1990-92. The activity indexing method using 1987 as the baseline year was shown not to be a reasonable method because it was based solely on one year's data. However, using only one year to base the relationship of aircraft maintenance activity to HW resulted in an unusually large spread in the data, as evidenced in Figures 16 and 17. The average activity index method consistently adjusted the measure of waste reduction progress for changes in activity and did not result in the large spread of data associated with the activity indexing method based on the 1987 data. The regression line fitted through the origin provided results that were consistent with the average activity index method; however, the method was more complex and time consuming. Based on the analysis, the average activity index was the preferred method. The advantage of using the regression method was that it provided a visual model of the relationship, and a coefficient of determination to quantify the strength of the relationship. Therefore, both the average activity indexing method, and the regression line fitted through the origin was recommended for use. Using DPAHs as the activity variable provided the most flexibility in the metric. This is because this variable was common to all of the bases in the study. All of the other maintenance related variables shown in Table 3 contribute to DPAHs. As a result, the effects of a mission transfer from one ALC to another ALC can be accounted for without having to wait several years to gather the data to re-establish the relationship between HW disposal and activity.

Proposed Metric Applied to the 1993 Quarterly Data. The proposed metric is to use the average activity index (1985-89 based) method or the regression model (1985-89 based) fitted through the origin to measure pollution prevention progress. These methods were preferred based on the previous analyses.

The average activity indexing method (1985-89) and the regression method fitted through the origin were applied to the 1993 quarterly hazardous waste disposal data to test these methods when compared to the percent change from the 1992 baseline. The 1992 baseline was picked since it is the baseline for the current Air Force metric for the years 1993-1999 as outlined in AFP 19-4. Because the baseline for the percent change method shifts from 1987 to 1992, this method indicated much smaller reductions in hazardous waste disposal than the previous analyses. The alternative methods, however, continue to be based on the levels prior to the implementation of pollution prevention. Therefore, these values indicate a greater reduction in hazardous waste disposal when compared to the percent change method.

Table 10 contains the results of this analysis. All of the centers with the exception of ALC-6 have a greater reduction in hazardous waste disposal when the alternative methods are applied. The data for ALC-6 is again influenced by the nearly 50% decrease in DPAHs and the relatively steady amount of hazardous waste disposal for 1993 when compared to the average 1985-89 amount.

TABLE 10

QUARTERLY PERCENT CHANGE IN 1993 HW DISPOSAL FOR THE VARIOUS METHODS

ALC	PERIOD	FROM 1992 BASELINE	FROM ACTIVITY INDEX PREDICTION (1985-89 BASED)	FROM REGRESSION PREDICTION THRU ORIGIN
ALC-1	1993-1	-28	-47	-49
ALC-1	1993-2	-8	-34	-35
ALC-1	1993-3	-22	-41	-42
ALC-1	1993-4	-60	-69	-69
ALC-2	1993-1	-19	-63	-63
ALC-2	1993-2	6	-54	-54
ALC-2	1993-3	-38	-72	-72
ALC-2	1993-4	-29	-69	-69
ALC-3	1993-1	10	-50	-51
ALC-3	1993-2	-22	-68	-68
ALC-3	1993-3	-20	-66	-66
ALC-3	1993-4	-2	-58	-59
ALC-4	1993-1	-34	-44	-44
ALC-4	1993-2	-63	-67	-67
ALC-4	1993-3	-10	-3	-3
ALC-4	1993-4	-69	-65	-66
ALC-6	1993-1	-17	38	39
ALC-6	1993-2	-36	1	1
ALC-6	1993-3	-17	31	32
ALC-6	1993-4	-46	-16	-15

Table 11 displays the descriptive statistics for this analysis and again indicates the advantage of using the methods that adjust the reduction in hazardous waste disposal based on the level of maintenance activity. The mean reduction is greater for the alternative methods, but the use of the methods is justified based on the strong to moderate correlation of hazardous waste disposal and DPAHs during the 1985-89 period prior to the Pollution Prevention Act.

TABLE 11

DESCRIPTIVE STATISTICS FOR TABLE 13 PERCENT CHANGE DATA

STATISTIC	FROM 1992 BASELINE	ACTIVITY INDEX (85-89 BASED)	REGRESSION THRU ORIGIN
MEAN	-26.2	-40.8	-41
MEDIAN	-22	-52	-52.5
STANDARD DEVIATION	21.6	33.6	34.0
MIN.	-69	-72	-72
MAX.	10	38	39

The box plot (Figure 19) further supports the above analysis. Clearly the distribution of the data for the 1992 based percent change had a greater mean than the two suggested alternatives. The average activity index method and the regression method fitted through the origin both produced virtually identical results. These two methods did have a greater standard deviation which was the result of the variation in the activity variables.

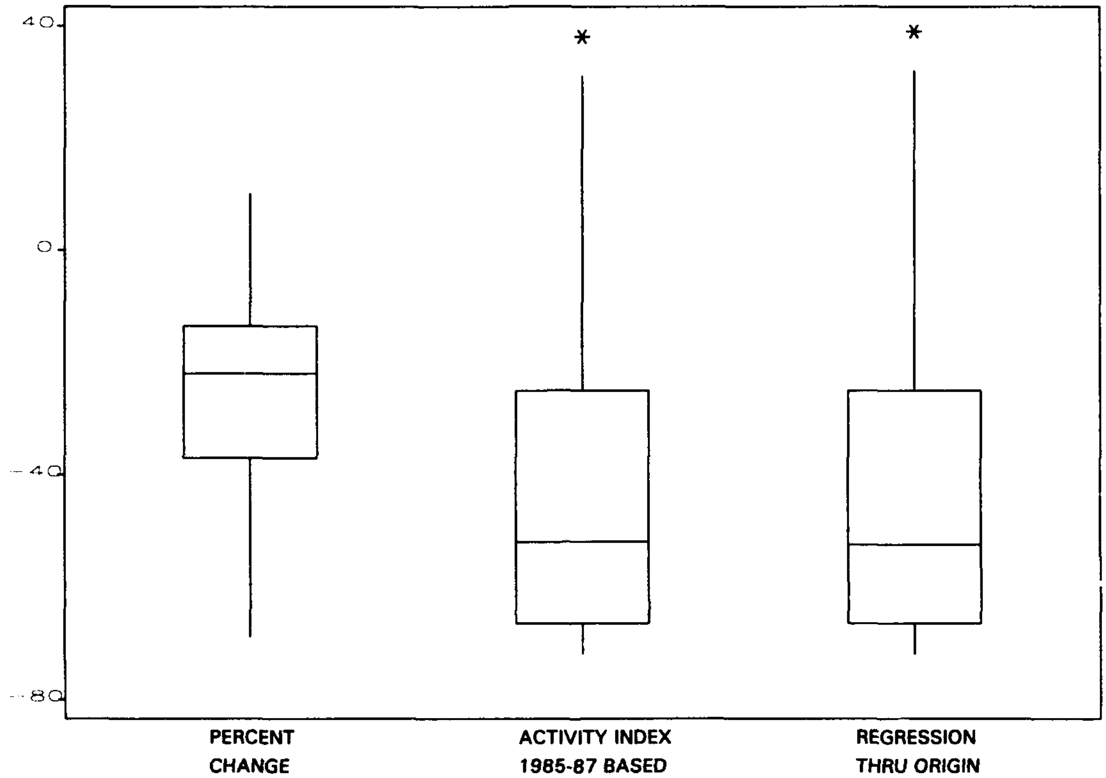

Figure 19. Box and Whisker Plots for the Various Methods Based on Quarterly Data

V. Conclusions and Recommendations

Conclusions

The first research objective was to determine if there is a statistically significant relationship between the amount of hazardous waste generated and the various measures of maintenance production activity at the ALCs.

Based on the correlation analysis, it can be concluded that there is indeed an association between the level of maintenance activity at the ALCs and the amount of hazardous waste disposal. The positive correlations indicated in Table 3 support this claim for all of the locations with the exception of ALC-5. The correlations in most cases were found to be strong to moderate.

The second research objective was to compare the current measurement method to the alternative methods of Activity Indexing and Predictive Regression Analysis for the ALC bases.

The methods which showed a decrease in the average percent reductions in hazardous waste disposal to account for decreases in activity levels without overreacting to the changes were the average activity index and the regression method fitted through the origin. These two methods normalized the percent reductions in hazardous waste disposal by shifting the distributions based on decreased levels of maintenance activity. These decreased levels of maintenance activity were indicated by the activity indices that were consistently less than one relative to the established baseline.

The average activity index method was the simpler of the two methods to apply and understand. The method does not require any sophisticated computer software or an understanding of regression analysis.

The current method used by the Air Force overstated actual progress made at reducing HW disposal when the reduced workload experienced at the ALCs for the years 1990-92 were taken into account. However, the results still indicate that significant progress was made during those years at reducing hazardous waste disposal at the ALCs even when the alternative methods were used. When the proposed method of normalizing the HW reduction progress was applied to the 1993 quarterly data, the results showed an greater reductions in HW when compared to the current metric.

Recommendations

The AFMC Environmental Management Division should review the results of the research and consider applying the averaged activity index method using the DPAH data to adjust the metric to account for changing activity levels for the ALCs where a positive correlation was observed. The average activity index could be adjusted on a periodic basis similar to adjusting the baseline in the percent change method. For instance, the average activity level and average HW disposal could be based on the years 1987-92 as opposed to 1985-89.

One suggestion for follow on study is determining if the same method can be applied to other commands. For instance, the number of sorties flown at an Air Combat Command or Air Mobility Command base may strongly correlate with the amount of hazardous waste generated at those bases. Another suggestion would be to determine if the method could be applied on a microscale. For instance, the number of hours dedicated to service calls within a Civil Engineering Squadron may strongly correlate with the amount of hazardous waste generated by that squadron. The usefulness of this method can also be investigated as a method to normalize the Toxic Release Inventory reporting data in the future. Another potential for follow-on study is to apply non-linear models to determine the fit of the data rather than the linear model.

Appendix A

Raw Data

CENTER	YEAR	HW DISPOSAL	AIRCRAFT	ENGINES	EXCHANGEABLES	MISSILES	DPAHs (000s)
ALC-1	1985	4252	445	0	152146	1226	8512
ALC-1	1986	3404	492	0	159583	108	8888
ALC-1	1987	2055	340	0	164661	244	8370
ALC-1	1988	1060	256	0	128262	239	7412
ALC-1	1989	1207	277	0	118607	280	7980
ALC-1	1990	964	317	0	122776	280	7760
ALC-1	1991	1891	301	0	109066	350	7235
ALC-1	1992	1327	365	0	85929	422	6523
ALC-2	1985	3767	67	927	185625	0	9281
ALC-2	1986	5600	71	582	229698	0	9637
ALC-2	1987	3510	81	467	257483	0	9566
ALC-2	1988	1762	64	289	166638	0	8542
ALC-2	1989	759	47	294	133282	0	9170
ALC-2	1990	1201	44	279	133481	0	9000
ALC-2	1991	1132	47	369	153683	0	8080
ALC-2	1992	1088	32	1250	113523	0	7698
ALC-3	1985	4944	295	0	200809	0	7577
ALC-3	1986	3787	264	0	192736	0	7905
ALC-3	1987	3358	243	0	184055	0	7686
ALC-3	1988	2261	224	0	150191	0	6771
ALC-3	1989	2078	224	0	150191	0	6710
ALC-3	1990	1285	226	0	144268	0	6745
ALC-3	1991	996	212	0	139354	0	6492
ALC-3	1992	1156	202	0	127294	0	6219
ALC-4	1985	94	0	0	27504	0	1802
ALC-4	1986	72	0	0	24228	0	1859
ALC-4	1987	52	0	0	26729	0	1817
ALC-4	1988	34	0	0	21550	0	1807
ALC-4	1989	27	0	0	23461	0	1703

CENTER	YEAR	HW DISPOSAL	AIRCRAFT	ENGINES	EXCHANGEABLES	MISSILES	DPAHs (000s)
ALC-4	1990	36	0	0	22415	0	1768
ALC-4	1991	19	0	0	17979	0	1516
ALC-4	1992	13	0	0	16094	0	1266
ALC-5	1985	294	296	0	230188	0	7693
ALC-5	1986	221	207	0	218686	0	7914
ALC-5	1987	313	158	0	206028	0	7752
ALC-5	1988	508	125	0	157922	0	7037
ALC-5	1989	400	162	0	167243	0	7837
ALC-5	1990	535	173	0	152883	0	8051
ALC-5	1991	1083	132	0	220246	0	6738
ALC-5	1992	965	205	0	112663	0	7437
ALC-6	1985	5999	173	1229	287034	0	9780
ALC-6	1986	5403	215	1573	291332	0	10560
ALC-6	1987	6309	191	1923	275526	0	10361
ALC-6	1988	5006	148	1226	212113	0	8873
ALC-6	1989	5623	138	1249	194686	0	8657
ALC-6	1990	6101	126	1124	165293	0	8568
ALC-6	1991	5395	115	726	149603	0	7465
ALC-6	1992	6049	94	1053	146963	0	7020

Center	Quarter	DPAHs (000s)	HW Disposal (tons)
ALC-1	1990-1	1778.38	199
	1990-2	1957.431	292
	1990-3	1934.512	256
	1990-4	1896.362	217
	1991-1	1787.818	281
	1991-2	1825.08	315
	1991-3	1743.683	415
	1991-4	1649.518	880
	1992-1	1581.174	336
	1992-2	1628.106	300
	1992-3	1653.593	394
	1992-4	1645.139	297
	1993-1	1554.653	237.6
	1993-2	1571.765	303.9
	1993-3	1492.532	257.52
	1993-4	1464.543	134.11
ALC-2	1990-1	2140.35	211
	1990-2	2275.537	313
	1990-3	2235.869	912
	1990-4	2277.105	529
	1991-1	2077.136	317
	1991-2	2051.125	438
	1991-3	1955.159	107
	1991-4	1943.356	270
	1992-1	1805.847	214
	1992-2	1896.294	348
	1992-3	2011.024	246
	1992-4	1927.739	280
	1993-1	1769.467	221
	1993-2	1852.42	287
	1993-3	1820.859	170
	1993-4	1848.279	192
ALC-3	1990-1	1711.149	714
	1990-2	1759.321	695
	1990-3	1710.558	843
	1991-1	1658.807	237
	1991-2	1639.168	218
	1991-3	1585.313	279
	1991-4	1678.954	268
	1992-1	1508.397	260
	1992-2	1547.002	359
	1992-3	1555.484	245

Center	Quarter	DPAHs (000s)	HW Disposal (tons)
	1992-4	1519.642	305
	1993-1	1426.488	318.2
	1993-2	1561.705	224.56
	1993-3	1520.405	231.56
	1993-4	1507.26	281.8
ALC-4	1990-1	424.481	10
	1990-2	439.64	10
	1990-3	439.401	12
	1990-4	459.241	4
	1991-1	415.734	6
	1991-2	417.438	9
	1991-3	328.851	5
	1991-4	349.734	11
	1992-1	324.654	7
	1992-2	321.112	9
	1992-3	317.433	5
	1992-4	296.258	8
	1993-1	267.531	4.69
	1993-2	258.255	2.68
	1993-3	215.163	6.5
	1993-4	208.853	2.24
ALC-5	1990-1	2034.702	181
	1990-2	2115.323	130
	1990-3	2123.32	141
	1990-4	2051.339	169
	1991-1	1817.925	82
	1991-2	1912.355	104
	1991-3	1789.206	122
	1991-4	1831.446	140
	1992-1	1659.13	102
	1992-2	1814.349	148
	1992-3	1910.821	152
	1992-4	1935.435	119
	1993-1	1820.434	164.94
	1993-2	1889.656	141
	1993-3	1905.641	147.7
	1993-4	1935.544	138
ALC-6	1990-1	2040.771	1775
	1990-2	2164.821	2054
	1990-3	2222.424	2533
	1990-4	2161.353	1863
	1991-1	1892.128	990
	1991-2	1832.379	1563
	1991-3	1852.334	1345
	1991-4	1867.313	1497

Center	Quarter	DPAHs (000s)	HW Disposal (tons)
	1992-1	1707.201	1364
	1992-2	1753.315	1545
	1992-3	1754.829	1588
	1992-4	1728.815	1552
	1993-1	1543.606	1255
	1993-2	1638.099	968
	1993-3	1628.57	1256
	1993-4	1652.783	819

Appendix B

Regression Equations

Based on Most Highly Correlated Variable
(Y-intercept Fitted)

ALC	r^2	Equation
ALC-1	0.8623	HW=12.5*Aircraft-2139
ALC-2	0.6005	HW=0.029*Exchangeables-2643
ALC-3	0.9697	HW=38.4*Aircraft-6321
ALC-4	0.5346	HW=0.0083*Exchangeables-149
ALC-6	0.3232	HW=0.94*Engines+4316

Based on Most Highly Correlated Variable
(Fitted Though the Origin)

ALC	r^2	Equation
ALC-1	0.6822	HW=6.98*Aircraft
ALC-2	0.4787	HW=0.016*Exchangeables
ALC-3	0.4825	HW=10.5*Aircraft
ALC-4	0.2539	HW=0.0023*Exchangeables
ALC-6	-2.852	HW=3.8*Engines

Based on DPAHs
(Y-intercept Fitted)

ALC	r^2	Equation
ALC-1	0.6509	HW=2.0*DPAHs-14080
ALC-2	0.4733	HW=3.0*DPAHs-24372
ALC-3	0.6241	HW=1.7*DPAHs-9050
ALC-4	0.3243	HW=0.27*DPAHs-436
ALC-6	0.2200	HW=0.28*DPAHs+2989

Based DPAHs
(Fitted Though the Origin)

ALC	r^2	Equation
ALC-1	0.1773	HW=0.297*DPAHs
ALC-2	0.1009	HW=0.338*DPAHs
ALC-3	0.2897	HW=0.457*DPAHs
ALC-4	0.0697	HW=0.031*DPAHs
ALC-6	-0.0520	HW=0.586*DPAHs

Multi-variable
(Y-intercept Fitted)

ALC	r^2	Equation
ALC-1	0.9217	HW=8.04*Aircraft+0.01*Exchangeables+1.34*Missiles+0.16*DPAHs-3888
ALC-2	0.8412	HW=1.65*Aircraft+1.85*Engines+0.02*Exchangeables+0.94*DPAHs-10703
ALC-3	0.9692	HW=-4.82*Aircraft+0.096*Exchangeables-1.85*DPAHs+1171
ALC-4	0.6949	HW=0.006*Exchangeables-0.014*DPAHs-78
ALC-6	0.4867	HW=-28.9*Aircraft+0.92*Engines+.006*Exchangeables+0.43*DPAHs+3752

Multi-variable
(Fitted through Origin)

ALC	r^2	Equation
ALC-1	0.8815	HW=8.82*Aircraft+0.028*Exchangeables+1.31*Missiles-0.66*DPAHs
ALC-2	0.7177	HW=25.5*Aircraft+1.13*Engines+0.02*Exchangeables-0.43*DPAHs
ALC-3	0.9688	HW=-1.16*Aircraft+0.086*Exchangeables-1.59*DPAHs
ALC-4	0.5946	HW=0.0078*Exchangeables-0.078*DPAHs
ALC-6	0.2783	HW=-46.7*Aircraft+0.50*Engines+0.003*Exchangeables+1.29*DPAHs

Bibliography

AFMC. "The Command -- An Integrated Team," Leading Edge, 4-12 (July 1993).

AFMC. FY92 Depot Maintenance Annual Report. AFMCP 66-65. WPAFB: HQ AFMC/IG, 1 September 1993.

Air Force Center for Environmental Excellence. "Case Study: Hazardous Materials Management at the Naval Weapons Station, Point Mugu, California," Federal Facilities Environmental Journal, 151-165 (Summer 1993).

Annamraju, Gopal. GM-13, Waste Minimization Program Manager, HQ AFMC/CEVV, Wright-Patterson Air Force Base, OH. Personal Interview. 15 December 1993.

Baker, Rachel Dickstein, Richard W. Dunford, and John L. Warren. Alternatives for Measuring Hazardous Waste Reduction. HWRIC # RR-056. Center for Economics Research, Research Triangle Park, North Carolina, April 1991.

Blackman Jr., William C. Basic Hazardous Waste Management. Boca Raton, Florida: Lewis Publishers, 1993.

Bower, Anthony G. and Peter D. Jacobson. "A DOD Strategy for Pollution Prevention," Federal Facilities Environmental Journal, 185-201 (Summer 1993).

Brunner, Paul G. "Case Study: Metrics and Partnership Drive McClellan AFB's Total Quality Efforts," Federal Facilities Environmental Journal, 349-359 (Autumn 1993).

Bush, Barbara L. "Measuring Pollution Prevention: How Do We Get There from Here?," Pollution Prevention Review, 431-443 (Autumn 1992).

Department of the Air Force. Air Force Pollution Prevention Program Action Memorandum. Washington: HQ USAF, 07 January 1993.

Department of the Air Force. Environmental Planning: Pollution Prevention. AFP 19-4. Washington: HQ USAF, 30 November 1992.

Devore, Jay L. Probability and Statistics for Engineering and the Sciences (Third Edition). Pacific Grove, California: Brooks/Cole Publishing Company.

Federal Register. "Guidance to Hazardous Waste Generators on the Elements of a Waste Minimization Program," Vol. 58, No 102, 31114-31120, 28 May 1993.

Freeman, Harry, Teresa Harten, Johnny Springer, Paul Randall, Mary Ann Curren, and Kenneth Stone. "Industrial Pollution Prevention: A Critical Review," Journal of the Air and Waste Management Association, Vol. 42, No 5: 618-656 (May 1992).

Graham, Ann B. "The Results of PPR's 1993 Survey: Industry Pollution Prevention Practices," Pollution Prevention Review, 369-381 (Autumn 1993).

Hatfield, Thomas H. and David H. Ott. "Measuring Source Reduction of Laboratory Hazardous Wastes," Journal of Environmental Health, 7-10 (October 1993).

Masters, Gilbert M. Introduction to Environmental Engineering and Science. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1991.

Neter, John and others. Applied Linear Regression Models (Second Edition). Boston: Richard D. Irwin Inc., 1989.

Statistix (Version 4.0). User's Manual. Saint Paul: Analytical Software, 1992.

Theodore, Louis and Young C. McGuinn. Pollution Prevention. New York: VanNostrand Reinhold, 1992.

United States Congress. Pollution Prevention Act of 1990. 42 U.S.C. 13101. 101st Congress, 2nd Session. Washington: GPO, 1990.

USEPA. Facility Pollution Prevention Guide. EPA/600/R-92/088. Washington: May 1992.

Vita

Edward C. Finke was born in the birthplace of aviation, Dayton, Ohio, on 19 June 1964. He graduated from Archbishop Alter High School in 1982, and attended Wright State University (WSU). He majored in Environmental Health Science, and minored in Business Management. In 1989, he graduated with honors from WSU and started work for the 645th Air Base Wing's Office of Environmental Management at Wright-Patterson Air Force Base (WPAFB). During his time at the 645th, he worked in the asbestos, hazardous waste, and PCB management programs, and was also a member of the spill response team. In June of 1993, he entered the Graduate Engineering and Environmental Management Program at the Air Force Institute of Technology's School of Engineering. His follow on assignment will be with Air Systems Command's Environmental Management Directorate.

Permanent Address: 726 Brunswick Drive
Enon, Ohio 45323

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average ... including the time for reviewing instructions, ... regarding this burden estimate ... Directorate for Information Operations ... Reduction Project (0704-0188), Washington ...

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1994	Master's Thesis

4. TITLE AND SUBTITLE
AN ANALYSIS OF ALTERNATIVE METHODS OF MEASURING HAZARDOUS WASTE REDUCTION PROGRESS AT AIR FORCE MATERIEL COMMAND'S AIR LOGISTIC CENTERS

5. FUNDING NUMBERS

6. AUTHOR(S)
Edward C. Finke, GS-12

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology, WPAFB OH. 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GEE/ENV/94S-10

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This study investigated the relationship between aircraft related maintenance activity and the amount of hazardous waste (HW) disposed of by Air Force Materiel Command's (AFMC) Air Logistic Centers (ALC). These ALCs, along with the Aircraft Guidance and Meteorology Center, generate approximately 76 percent of the HW generated by the Air Force. The activity indexing and least squares curve fitting methods were used to predict the amount of HW that would have been disposed of based on the relative level of aircraft related maintenance activity had no pollution prevention efforts been implemented. these predictions were then compared to what historically occurred as the measure of pollution prevention progress. The results indicated that there is a moderate to strong correlation between HW disposal and aircraft related maintenance activity at five of the six bases studied. The activity indexing method based on an average ratio of HW to maintenance activity, and the method of fitting a least squares regression line through the origin were determined to be the most useful methods of measuring pollution prevention progress at the ALCs.

14. SUBJECT TERMS
Environmental Metrics, Hazardous Waste, Pollution Prevention, Waste Reduction, Waste Minimization, Waste

15. NUMBER OF PAGES
112

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500